

March 31, 1999

Estimating Risk from Disposal of Solvent Contaminated Shop Towels and Wipes in Municipal Landfills

Final

Prepared for

**Office of Solid Waste
U.S. Environmental Protection Agency
401 M Street, SW (5307W)
Washington, DC 20460**

**EPA Contract Number 68-W98-085
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Prepared by

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1.0 Introduction

Disposable shop towels and wipers are used throughout industry for equipment and other facility cleaning and degreasing operations. During the cleaning operations, these towels and wipers frequently are contaminated with solvents. Upon disposal, the "spent" shop towels are identified as hazardous waste under federal regulations if the solvent used is a characteristic or listed solvent (40 CFR 261 Appendix VII, F001 through F005, November 14, 1997).

The U.S. Environmental Protection Agency (EPA) has been petitioned to address the issue of exempting disposable wipers contaminated with listed or characteristic solvents from hazardous waste regulations. Regulated industries argue that, when small amounts of solvent are used on each shop towel, minimal risk is posed from their disposal in municipal landfills rather than in Subtitle C regulated landfills. The EPA Office of Solid Waste (OSW) recently conducted a study to identify use and disposal patterns and practices for shop towels and wipers. This risk assessment evaluates the human health risk posed if wipers contaminated with listed hazardous solvents are exempted from federal and state regulations and disposed of in municipal landfills.

Residents living near municipal landfills receiving solvent-contaminated spent wipes may be exposed to vapors or contaminated groundwater. This document evaluates the potential health risks associated with these exposures. The following steps were completed: the waste was characterized, the municipal landfill scenario defined, the fate and transport potential of the constituents determined, the receptors and exposure pathways identified, and the resulting risks estimated. A final section includes the references cited in this document. Appendixes to this document provide more detail on the models used in this risk analysis.

2.0 Waste Stream Characterization

The disposable shop towel and wiper waste stream may include many types of shop towels and wipers that may be contaminated with a variety of solvents, some of which may be listed or characteristic wastes. These waste streams may be produced by both large-quantity generators (LQGs) and small-quantity generators (SQGs). According to a recent study by EPA's Office of Solid Waste (OSW), the LQG is assumed to generate a total of 120 wipers per day and the SQG is assumed to generate a total of 30 contaminated wipers per day.

There has been no attempt to characterize the matrix effects of the individual shop towel or wiper products. Instead the towels and wipers have been characterized as a single product, hereafter referred to as a wiper. These products are assumed to weigh 10.48 g each (O'Leary, 1997) and to be contaminated with an equal weight of solvent at disposal. The solvent is not assumed to be bound to the wiper matrix; thus, all solvents are assumed to be free in the landfill environment for volatilizing to air and/or leaching to groundwater. Thus, the disposal of each contaminated wiper represents the addition of 10.48 g of a solvent in the landfill. These assumptions are based on data collected during the economic analysis of this waste listing determination.

The solvent contaminants examined in this risk assessment include all constituents listed in Appendix VII for F001 through F005 (40 CFR 261.31):

F001 The following spent halogenated solvents used in degreasing: Tetrachloroethylene, trichloroethylene, methylene chloride, 1,1,1-trichloroethane, carbon tetrachloride, and chlorinated fluorocarbons; all spent solvent mixtures/blends used in degreasing containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those solvents listed in F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures. (T)

F002 The following spent halogenated solvents: Tetrachloroethylene, methylene chloride, trichloroethylene, 1,1,1-trichloroethane, chlorobenzene, 1,1,2-trichloro-1,2,2-trifluoroethane, ortho-dichlorobenzene, trichlorofluoromethane, and 1,1,2-trichloroethane; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above halogenated solvents or those listed in F001, F004, or F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures. (T)

F003 The following spent non-halogenated solvents: Xylene, acetone, ethyl acetate, ethyl benzene, ethyl ether, methyl isobutyl ketone, n-butyl alcohol, cyclohexanone, and methanol; all spent solvent mixtures/blends containing, before use, only the above spent non-halogenated solvents; and all spent solvent mixtures/blends containing, before use, one or more of the above non-halogenated solvents, and, a total of ten percent or more (by volume) of one or more of those solvents listed in F001, F002, F004, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures. (I)*

F004 The following spent non-halogenated solvents: Cresols and cresylic acid, and nitrobenzene; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above non-halogenated solvents or those solvents listed in F001, F002, and F005; and still bottoms from the recovery of these spent solvents and spent solvent mixtures. (T)

F005 The following spent non-halogenated solvents: Toluene, methyl ethyl ketone, carbon disulfide, isobutanol, pyridine, benzene, 2-ethoxyethanol, and 2-nitropropane; all spent solvent mixtures/blends containing, before use, a total of ten percent or more (by volume) of one or more of the above non-halogenated solvents or those solvents listed in F001, F002, or F004; and still bottoms from the recovery of these spent solvents and spent solvent mixtures. (I,T)

The quantity of each solvent is assumed to equal the weight of each wiper on which it is assumed to be used. Thus, the risk from each solvent is estimated individually and no risk to multiple contaminants has been assessed. All wipers from a facility are assumed to be contaminated with a single solvent and each risk number in the results section (Section 6.0) represents risk from a single solvent disposed of by a single generator at a single landfill.

3.0 Site Characterization

This section provides general information on climate, soil types, and landfill parameters.

3.1 Climate

Solvent-contaminated wipers are generated nationwide and, therefore, the locations selected for modeling should be representative of the central tendency and high-end meteorologic conditions in the United States. For this analysis, 29 meteorologic regions were evaluated (see Figure 3-1). The meteorological regions are the 29 regions identified in an assessment conducted for EPA's Superfund Soil Screening Levels (SSLs) program (EQM, 1993). These meteorologic data are considered to be representative of both broad geographic climate regions which characterize the continental US and of more narrowly defined meteorological stations for which data is available throughout the US. This section describes the methodology used to select these 29 regions.

In the Superfund analysis, meteorological data primarily from the Support Center for Regulatory Air Models (SCRAM) Bulletin Board, which provides information on 200 meteorological stations in the United States, was used to subdivide the continental US into 29 meteorological regions. The SCRAM Bulletin Board can be accessed at <http://www.epa.gov/scram001>. The 29 meteorological stations are distributed among nine general climate regions based on meteorological representativeness and variability across each region. These regions are: North Pacific Coastal; South Pacific Coastal; Southwest; Northwest Mountains; Central Plains; Southeast; Midwest; Northern Atlantic; and South Florida.

Once the regions were identified, large scale regional average meteorological conditions were used to select representative meteorological stations within each of 29 regions. Based on statistical analyses, the 29 meteorological stations were determined to be representative of the 200 meteorological stations in the U.S. for which data is available from the SCRAM Bulletin Board.

The 29 regions were then further refined using a geographic information system (GIS) platform which integrates climate and meteorologic data from various geographic data bases. The GIS data was used to construct more accurate meteorologic-based boundaries around each station. This effort was undertaken to ensure that each region represents an area in which the meteorological conditions are most similar to conditions measured at the meteorological station. As a first step in this process, the boundaries were adjusted to correspond to Bailey's ecological divisions and provinces. (Bailey et al., 1994) Bailey's regions are defined primarily on physiography and climate. Bailey recognizes all natural ecosystems by differences in climatic

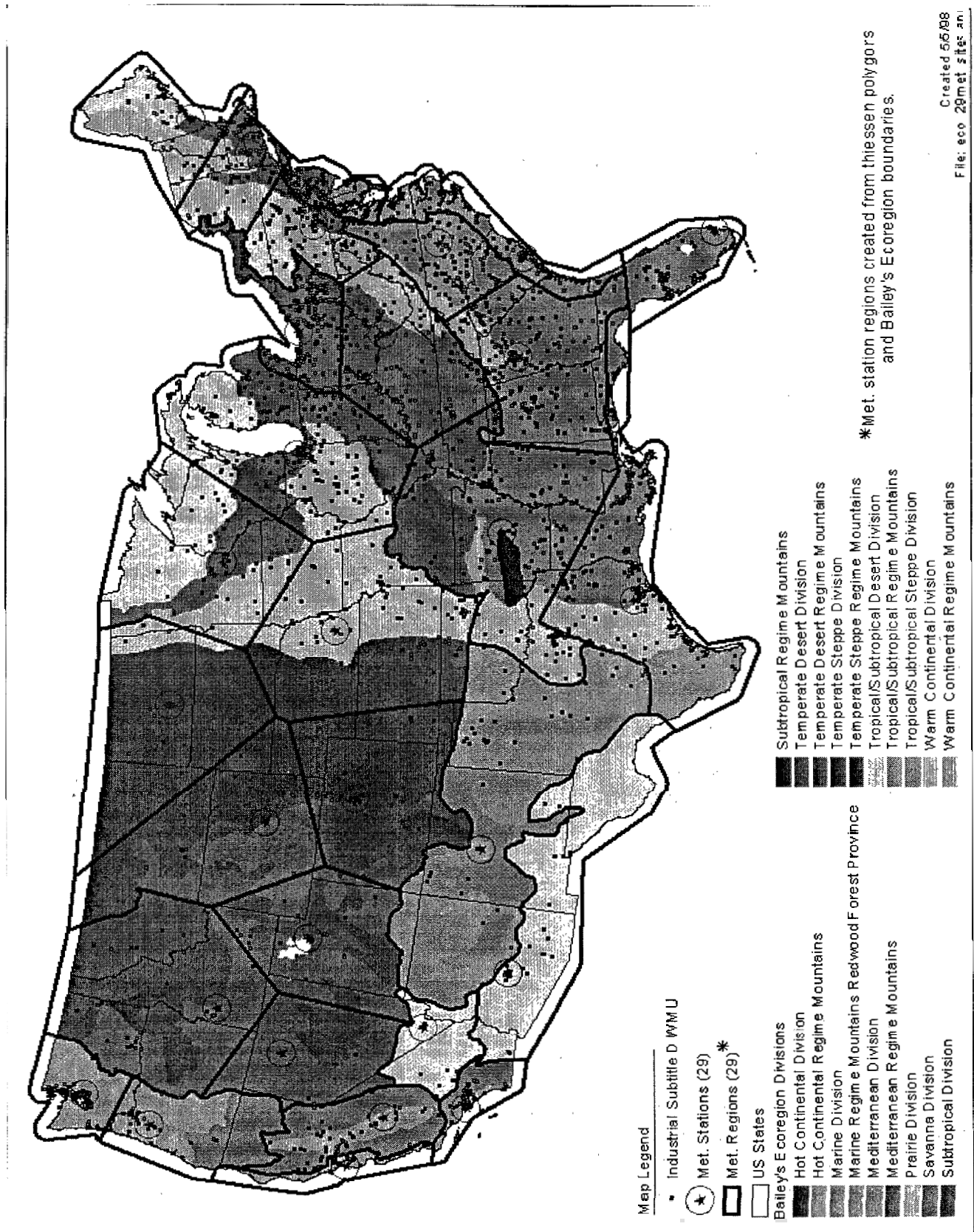


Figure 3-1. Meteorological station regions.

regime. Climate, as a source of energy and moisture, acts as the primary control of the ecosystem. Other important criteria for establishing limits of ecosystems are soil and landform. Thus, by using Bailey's ecoregions to help in defining the boundaries of the climate regions landform, soil and climate are all considered in setting the boundaries.

Next, the Agency evaluated other physiographic features which are not addressed in Bailey's criteria but which are likely to influence climate conditions in certain atypical climatic areas. This was done in an effort to ensure that the following unique regions were addressed within the selected regions: coastal regimes which are dominated by coastal climate effects - these are generally narrow regions which stretch about 25 to 50 miles inland; tropical/subtropical and arid/semi-arid divisions in the southwestern US; and northwestern regions within Washington, Oregon, and California which are characterized by the more humid marine/redwood or Mediterranean mountain regimes. General wind regimes were also considered in the defining the 29 regions. The data from the 29 selected meteorologic stations are considered to be representative of the climate regions and all modeling is conducted using these data. Each of these regions is represented by a meteorologic site. The climatic data for the sites used in this analysis are presented in Table 3-1. The most important climate parameters for this analysis are precipitation, which effects leaching to groundwater; windspeed, which increases plume dispersion; and temperature, which increases volatilization. The meteorologic conditions affect both the nongroundwater risk through the air emissions and the groundwater risk through the generation of leachate. The central tendency location selected for this analysis was Lincoln, NE.

Table 3-1. Meteorological Data for Modeled Sites

Parameter	Units	Houston Lincoln		Reference
Average annual precipitation	in/yr	47	29	International Station Meteorological Climate Summary, June 1992.
Average annual precipitation	cm/yr	119	75	Calculated
Average annual evapotranspiration	cm/yr	66	47	Calculated
Average annual runoff	in/yr	5	1	Leeden, 1990
Average annual runoff	cm/yr	14	3	Calculated
Average annual temperature	°F	69	51	International Station Meteorological Climate Summary, June 1992.
Average annual temperature	K	294	284	Calculated
Mean annual windspeed	knots	8	10	International Station Meteorological Climate Summary, June 1992.
Mean annual windspeed	m/s	4	5	Calculated

This location was the central tendency location used in the Hazardous Waste Identification Rule to represent median climatic conditions in the United States. In order to select a high-end location, several warm and wet locations were examined to see which one produced high risk both through the air and through the groundwater pathway. The highest risk by each pathway individually is not necessarily the location demonstrating the highest overall risk. For example, the location showing the highest air pathway risk is Phoenix, AZ; however, this location is so

arid that landfill leachate volume is very low or nonexistent, eliminating the groundwater pathway from consideration. Table 3-2 presents the comparative air emissions and leachate concentration data for the sites selected for consideration, Houston, TX, Charleston, SC, and Miami, FL. Houston, TX was selected as the high end location based on combined risk from groundwater and air emissions.

Table 3-2. Comparative Air Emissions and Leachate Concentration

Constituent	CAS No.	Charleston	Houston	Miami	Charleston	Houston	Miami
		Average Emission Rates (g/m ² -sec)			Average Leachate Concentrations (mg/L)		
Carbon tetrachloride	56235	1.92E-07	1.92E-07	1.92E-07	1.10E-01	1.12E-01	1.09E-01
Ethyl ether	60297	2.59E-07	2.60E-07	2.59E-07	1.89E+01	1.95E+01	1.83E+01
Methanol	67561	3.11E-08	3.11E-08	3.12E-08	1.15E+01	1.20E+01	1.13E+01
Acetone	67641	7.59E-08	7.59E-08	7.60E-08	7.69E+00	8.02E+00	7.53E+00
Butanol	71363	4.51E-09	4.47E-09	4.53E-09	1.19E+00	1.24E+00	1.17E+00
Benzene	71432	1.05E-07	1.05E-07	1.05E-07	1.28E-01	1.33E-01	1.26E-01
Trichloroethane, 1,1,1-	71556	1.90E-07	1.90E-07	1.90E-07	1.72E-01	1.76E-01	1.70E-01
Methylene chloride	75092	2.16E-07	2.16E-07	2.16E-07	1.32E+00	1.36E+00	1.30E+00
Carbon disulfide	75150	3.06E-07	3.06E-07	3.06E-07	2.59E+00	2.60E+00	2.57E+00
Trichlorofluoromethane	75694	2.96E-07	2.96E-07	2.96E-07	1.45E-01	1.48E-01	1.44E-01
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76131	3.07E-07	3.07E-07	3.07E-07	1.94E-01	1.95E-01	1.94E-01
Isobutyl alcohol	78831	7.99E-09	7.95E-09	8.03E-09	1.48E+00	1.54E+00	1.45E+00
Methyl ethyl ketone	78933	4.81E-08	4.80E-08	4.81E-08	3.60E+00	3.75E+00	3.53E+00
Trichloroethane, 1,1,2-	79005	6.30E-08	6.30E-08	6.30E-08	6.37E-01	6.48E-01	6.32E-01
Trichloroethylene	79016	1.13E-07	1.13E-07	1.13E-07	1.27E-01	1.30E-01	1.26E-01
Nitropropane, 2-	79469	1.03E-07	1.03E-07	9.67E-08	6.38E+00	6.52E+00	5.51E+00
o-Xylene	95476	4.13E-08	4.13E-08	4.13E-08	3.26E-01	3.27E-01	3.26E-01
Cresol, o-	95487	8.19E-10	8.09E-10	8.17E-10	2.74E-01	2.83E-01	2.70E-01
Dichlorobenzene, 1,2-	95501	2.67E-09	2.67E-09	2.67E-09	2.12E-02	2.17E-02	2.10E-02
Nitrobenzene	98953	2.12E-09	2.06E-09	2.18E-09	7.95E-01	8.13E-01	7.87E-01
Ethylbenzene	100414	2.24E-08	2.24E-08	2.24E-08	9.32E-03	9.70E-03	9.14E-03
Cresol, p-	106445	3.59E-10	3.60E-10	3.57E-10	4.37E-02	4.56E-02	4.27E-02
Methyl isobutyl ketone	108101	2.50E-08	2.50E-08	2.50E-08	5.75E-01	6.00E-01	5.64E-01
m-Xylene	108383	4.02E-08	4.02E-08	4.02E-08	2.79E-01	2.80E-01	2.79E-01
Cresol, m-	108394	4.85E-10	4.88E-10	4.77E-10	1.02E-01	1.06E-01	9.96E-02
Toluene	108883	5.89E-08	5.89E-08	5.88E-08	4.12E-02	4.26E-02	4.05E-02
Chlorobenzene	108907	3.93E-08	3.93E-08	3.93E-08	7.21E-02	7.38E-02	7.13E-02
Cyclohexanone	108941	8.31E-09	8.33E-09	8.25E-09	3.62E+01	3.77E+01	3.46E+01
Ethoxyethanol, 2-	110805	1.14E-09	1.20E-09	1.09E-09	1.79E+01	1.85E+01	1.76E+01

3.2 Landfill Parameters

Landfill volume determines the effective concentration of solvents in the landfill, and landfill surface area is used to estimate air emission and dispersion and leachate concentrations. Landfill dimensions were determined from the municipal landfill descriptions submitted by the

State of Texas and the distribution of landfill areas for municipal landfills from the national survey of solid waste (municipal) landfill facilities conducted in support of the toxicity characteristic (U.S. EPA, 1988). The landfill is assumed to have a lifetime of 30 yrs and to have a single cell open each year; thus, each annual cell has an area 1/30th of the total landfill area. The distribution of landfill and cell areas derived from the survey is presented in Table 3-3. The high end landfill area for the non-groundwater pathway is always the 10th percentile value because it represents the higher effective concentration of constituent in the landfill. For the groundwater pathway the high end landfill area may be some other landfill area, because of the interaction of effective landfill concentration of constituents and the DAFs estimated based on landfill area. DAFs are indirectly related to the landfill area, however, area is also inversely related to effective concentrations of constituents in the landfill. The high end landfill area may be neither the 10th or the 90th percentile, but instead some intermediate size. A sensitivity analysis has been conducted for landfill area has been performed and the results are presented in Appendix F.

Information on depth or total capacity of landfills corresponding to the nationwide distribution of landfill areas was not available. Therefore, to determine a realistic value, these areas were compared to the areas reported for landfills in Texas. Texas landfills were identified that most closely corresponded to the 50th and 10th percentile landfills from the nationwide distribution. The landfills with the corresponding areas were selected as representative of central tendency and small landfills, respectively. There were three landfills in Texas that corresponded to the 50th percentile area; however, no landfill as small as 8,090 m² was identified. Therefore, the two landfills with areas of 12,144 m² were used to estimate an appropriate depth for landfills of this area. [Note: A sensitivity analysis conducted for air emissions from landfill cells indicates that small differences in surface area of landfill cells makes no significant difference in the vapor air concentrations estimated at the receptor location within the limits of this analysis (RTI, 1998).] The depths of the landfills identified as corresponding to the 50th and 10th percentile ranged from 8 (2.4 m) to 30 ft (9.1 m) with an average depth of 18 ft (5.5 m). The landfill corresponding to 3 acres and 8 ft deep received only 32 tons of waste in 1996. This data point "n" was determined to be an outlier when compared to the distribution of municipal landfills. The depth of 18 ft (5.5 m) was chosen for use in this analysis for both areas. The data used to estimate the landfill depths are presented in Table 3-4. The total distribution of landfill depths

Table 3-3. Distribution of Municipal Landfill Areas

Total landfill area, m ²	Landfill cell area, m ²	Cumulative percentage
4,000	133.3	0
8,090	269.7	10
20,200	673.3	25
60,700	2,023	50
194,000	6,467	75
420,000	14,000	90
9,350,000	311,667	100

Table 3-4. Texas Landfill Data Used to Estimate Landfill Depths

Landfill permit number	Total landfillable area, acres (m ²)	Maximum depth, ft (m)
630 ^a	3 (12,144)	8 (2.4)
1,418	3 (12,144)	18 (5.5)
664	15 (60,700)	30 (9.1)
1,267	15 (60,700)	18 (5.5)
1,520	15 (60,700)	20 (6.1)

^a Determined to be outlier based upon annual waste volume

reported for Texas landfills was examined and the 10th (4 m) and 90th (28 m) percentile depths were identified. This distribution is presented in Table 3-5. For this analysis the depth of the landfill is used to determine the annual capacity of the landfill cell based upon a 30-yr lifetime for the landfill. A sensitivity analysis was performed for landfill depth using the values. The results indicate that the maximum effect on risk was to decrease risk by less than an order of magnitude at the 90th percentile value for depth and increase risk by a factor of 2 or less at the 10th percentile value. This may be an over-estimation of annual waste volume because many landfills in the Texas survey reported estimated lifetimes in excess of 30 years. A discussion of the landfill depth sensitivity analysis is presented in Appendix F. Appendix F documents sensitivity analyses that have been performed for several parameters that are associated with the greatest uncertainty in this analysis.

Table 3-5 Distribution of Landfill Depths (Texas Landfill Survey)

Percentile	Depth (ft)	Depth (m)
10	12	4
50	35	11
90	92.5	28
Mean	47	14

3.3 Soils Data

Soils data generally are required for ground water fate and transport modeling. However, for this risk assessment, generic dilution/attenuation factors (DAFs) were used to assess groundwater risk; no site-specific or constituent-specific groundwater modeling was performed, thus, soil transport was inconsequential. Therefore, general soil parameters representing a central tendency soil type were used to represent the daily cover material. The most common soil type in the United States is silt loam soil. Soil type is a fractal parameter. That is, the most common soil type in the nation is also the most common in each region, and in each smaller division of area. Thus, the most common soil type is appropriate for use in this analysis. The parameters for silt loam soil are presented in Table 3-6.

Table 3-6. Summary of Silt Loam Soil Parameters

Parameter	Units	Central tendency	Reference
Bulk density of soil at deposition location	g/cm ³	1.46	Calculated from saturated volumetric water content
Saturated volumetric water content of soil	mL/cm ³	0.45	Carsel and Parish, 1988
Saturated hydraulic conductivity	cm/yr	3942	Carsel and Parish, 1988
Soil-specific exponent representing moisture retention	unitless	5.3	Clapp and Hornburger, 1978
Fraction of organic carbon in soil at deposition location	unitless	0.012	STATSGO

4.0 Environmental Fate and Transport Modeling

This section reviews the models and assumptions used to predict environmental fate and transport of the solvents released from wipers disposed in municipal landfills. Detailed discussions of the models are provided in Appendices A and B.

Potential release mechanisms for the municipal landfill include volatile emissions and leaching (Figure 4-1). It is assumed that the landfill has erosion and runoff controls and that the active landfill cell has a daily cover applied. The remainder of the landfill is assumed to have a permanent cap. Therefore, no runoff, erosion, or particulate emissions are considered for the landfill.

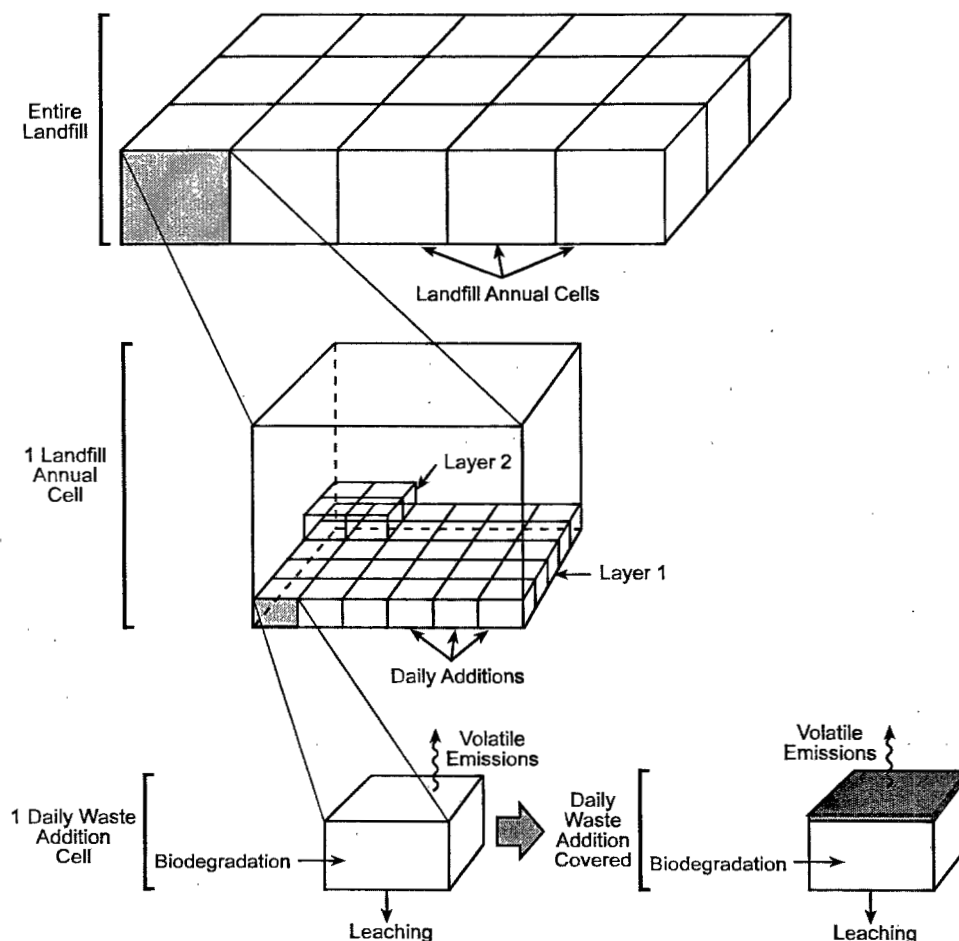


Figure 4-1. Landfill partitioning schematic.

The waste constituents addressed in this risk assessment are listed in Section 2.0. Physical and chemical properties of these constituents that are used in this analysis are listed in Table 4-1. These physical and chemical properties are used to model the environmental fate and transport processes.

4.1 Partitioning Model

A spreadsheet model has been developed based on the equations used to estimate the partitioning of pesticide products in the environment (Jury et al., 1983, 1984, 1990). These equations partition the waste in the landfill to waste, air, and pore water and calculate potential losses from leaching, volatilization, and degradation. The appropriateness of including degradation in the landfill scenario is a debatable point. This issue is addressed in a sensitivity analysis presented in Appendix F. In the sensitivity analysis the effect of assuming a zero degradation of solvent constituents in the landfill is compared to the risk and HQ estimated including degradation in the analysis.

For this analysis, the partitioning model has been adapted to represent emissions specifically from a municipal landfill. The regulations presented in 40 CFR 258, Criteria for Municipal Solid Waste Landfills, January 20, 1998, indicate that the following criteria must be met:

- Daily waste additions not to exceed 2.5 ft in depth
- Daily soil cover of 6 in.
- Cap thickness of at least 30 in.

These requirements have been included in the model so that regulations are not violated. Waste is assumed to be collected 350 d/yr and each daily addition volume is placed in a "daily pile" in the landfill so that the height does not exceed 2.5 feet. The daily pile is assumed to emit vapors for 12 hours prior to the application of daily cover. On day 2, the daily waste is placed in a second daily pile assumed to be adjacent to the initial daily pile. On day 2, emissions are estimated from daily pile 2 (uncovered for 12 hours) and from daily pile 1 through the daily soil cover. The number of daily piles is estimated based on the area of the landfill cell divided by the area of each daily pile. Additions of new daily piles continue until the area of the cell is filled with a layer of daily waste. When a layer is completed, a second layer is begun by placing the next daily waste addition on top of the initial daily wastepile. This process continues until the annual cell is filled. When the annual cell is filled, a 30-inch-thick landfill cap is applied. Minimal emissions are estimated to continue through the cell cap for the remainder of the modeling duration (30-year lifetime of the landfill and 40 years thereafter). The modeling duration has been selected to cover the peak period for leachate concentration generation, which frequently occurs after landfill closure. Figure 4-1 depicts the landfill addition scenario as modeled. The landfill model sums the emissions from the uncovered wastepiles, the covered wastepiles (daily cover), and the capped cells in a dynamic model. The partitioning model and equations are discussed in greater detail in Appendix A. The input parameters used in the partitioning model are presented in Table 4-2.

Table 4-1. Chemical Properties

Compound	CAS	K _{ow}	K _{ow} source	Henry's Law constant (atm-m ³ /mol)	HLC source	Diffusion coefficient in water (cm ² /s)	Diffusion coefficient in air (cm ² /s)	Diffusion coefficient source
Carbon tetrachloride	56-23-5	5.37E+02	SCDM	3.04E-02	SCDM	8.80E-06	7.80E-02	Water8
Ethyl ether	60-29-7	6.76E+00	SCDM	3.30E-02	SCDM	9.30E-06	7.40E-02	Water8
Methanol	67-56-1	1.95E-01	SCDM	4.55E-06	SCDM	1.64E-05	1.50E-01	Water8
Acetone	67-64-1	5.75E-01	SCDM	3.88E-05	SCDM	1.14E-05	1.24E-01	Water8
Butanol	71-36-3	7.08E+00	SCDM	8.81E-06	SCDM	9.30E-06	8.00E-02	Water8
Benzene	71-43-2	1.35E+02	SCDM	5.58E-03	Calculated	9.80E-06	8.80E-02	Water8
1,1,1-Trichloroethane	71-55-6	3.02E+02	SCDM	1.72E-02	SCDM	8.80E-06	7.80E-02	Water8
Methylene chloride	75-09-2	1.78E+01	SCDM	2.19E-03	SCDM	1.17E-05	1.01E-01	Water8
Carbon disulfide	75-15-0	1.00E+02	SCDM	3.02E-02	SCDM	1.00E-05	1.04E-01	Water8
Trichlorofluoromethane	75-69-4	3.39E+02	SCDM	9.70E-02	SCDM	9.70E-06	8.70E-02	Water8
Dichlorodifluoromethane	75-71-8	1.45E+02	SCDM	3.43E-01	SCDM	8.00E-06	8.00E-02	NA
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	1.45E+03	SCDM	4.82E-01	SCDM	8.20E-06	7.80E-02	Water8
Isobutyl alcohol	78-83-1	5.62E+00	SCDM	1.20E-05	SCDM	9.30E-06	8.60E-02	Water8
Methyl ethyl ketone	78-93-3	1.91E+00	SCDM	5.59E-05	SCDM	9.80E-06	8.08E-02	Water8
1,1,2-Trichloroethane	79-00-5	1.12E+02	SCDM	9.13E-04	SCDM	8.80E-06	7.80E-02	Water8
Trichloroethylene	79-01-6	5.13E+02	SCDM	1.03E-02	SCDM	9.10E-06	7.90E-02	Water8
2-Nitropropane	79-46-9	7.41E+00	SCDM	1.23E-04	SCDM	1.01E-05	9.23E-02	Water8
o-Xylene	95-47-6	1.35E+03	SCDM	5.19E-03	Calculated	1.00E-05	8.70E-02	Water8
o-Cresol	95-48-7	9.77E+01	SCDM	1.20E-06	SCDM	8.30E-06	7.40E-02	Water8
1,2-Dichlorobenzene	95-50-1	2.69E+03	SCDM	1.90E-03	SCDM	7.90E-06	6.90E-02	Water8
Nitrobenzene	98-95-3	6.92E+01	SCDM	2.40E-05	SCDM	8.60E-06	7.60E-02	Water8
Ethylbenzene	100-41-4	1.38E+03	SCDM	7.88E-03	SCDM	7.80E-06	7.50E-02	Water8
p-Cresol	106-44-5	8.91E+01	SCDM	7.92E-07	SCDM	1.00E-05	7.40E-02	Water8
Methyl isobutyl ketone	108-10-1	1.55E+01	SCDM	1.38E-04	Calculated	7.80E-06	7.50E-02	Water8
m-Xylene	108-38-3	1.58E+03	SCDM	7.34E-03	SCDM	7.80E-06	7.00E-02	Water8
m-Cresol	108-39-4	9.33E+01	SCDM	8.65E-07	SCDM	1.00E-05	7.40E-02	Water8
Toluene	108-88-3	5.62E+02	SCDM	6.64E-03	SCDM	8.60E-06	8.70E-02	Water8
Chlorobenzene	108-90-7	7.24E+02	SCDM	3.70E-03	SCDM	8.70E-06	7.30E-02	Water8
Cyclohexanone	108-94-1	6.46E+00	SCDM	8.41E-06	SCDM	8.62E-06	7.84E-02	Water8
2-Ethoxyethanol	110-80-5	7.94E-01	SCDM	1.23E-07	SCDM	9.57E-06	9.47E-02	Water8
Pyridine	110-86-1	4.68E+00	SCDM	8.88E-06	SCDM	7.60E-06	9.10E-02	Water8
Tetrachloroethylene	127-18-4	4.68E+02	SCDM	1.84E-02	SCDM	8.20E-06	7.20E-02	Water8
Ethyl acetate	141-78-6	4.90E+00	SCDM	1.38E-04	SCDM	9.66E-06	7.32E-02	Water8
Xylenes (total)	1330-20-7	1.48E+03	SCDM	6.04E-03	Calculated	9.34E-06	7.14E-02	Water8

(continued)

Table 4-1. (continued)

Compound	CAS	Vapor pressure at approximately 25 °C (atm)	VP source	Solubility (mg/L)	Solubility source	Molecular weight (g/mol)
Carbon tetrachloride	56-23-5	1.51E-01	SCDM	7.93E+02	SCDM	153.82
Ethyl ether	60-29-7	7.07E-01	SCDM	6.05E+04	SCDM	74.12
Methanol	67-56-1	1.66E-01	SCDM	1.00E+06	SCDM	32.04
Acetone	67-64-1	3.03E-01	SCDM	1.00E+06	SCDM	58.08
Butanol	71-36-3	8.55E-03	SCDM	7.40E+04	SCDM	74.12
Benzene	71-43-2	1.25E-01	SCDM	1.75E+03	SCDM	78.11
1,1,1-Trichloroethane	71-55-6	1.63E-01	SCDM	1.33E+03	SCDM	133.4
Methylene chloride	75-09-2	5.70E-01	SCDM	1.30E+04	SCDM	84.93
Carbon disulfide	75-15-0	4.72E-01	SCDM	1.19E+03	SCDM	76.14
Trichlorofluoromethane	75-69-4	1.06E+00	SCDM	1.10E+03	SCDM	137.37
Dichlorodifluoromethane	75-71-8	6.38E+00	SCDM	2.80E+02	SCDM	120.91
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	4.37E-01	SCDM	1.70E+02	SCDM	187.38
Isobutyl alcohol	78-83-1	1.38E-02	SCDM	8.50E+04	SCDM	74.12
Methyl ethyl ketone	78-93-3	1.25E-01	SCDM	2.23E+05	SCDM	72.11
1,1,2-Trichloroethane	79-00-5	3.06E-02	SCDM	4.42E+03	SCDM	133.4
Trichloroethylene	79-01-6	9.67E-02	SCDM	1.10E+03	SCDM	131.39
2-Nitropropane	79-46-9	2.37E-02	SCDM	1.70E+04	SCDM	89.09
o-Xylene	95-47-6	8.70E-03	SCDM	1.78E+02	SCDM	106.17
o-Cresol	95-48-7	3.93E-04	SCDM	2.60E+04	SCDM	108.14
1,2-Dichlorobenzene	95-50-1	1.79E-03	SCDM	1.56E+02	SCDM	147
Nitrobenzene	98-95-3	3.22E-04	SCDM	2.09E+03	SCDM	123.11
Ethylbenzene	100-41-4	1.26E-02	SCDM	1.69E+02	SCDM	106.17
p-Cresol	106-44-5	1.45E-04	SCDM	2.15E+04	SCDM	108.14
Methyl isobutyl ketone	108-10-1	2.62E-02	SCDM	1.90E+04	SCDM	100.16
m-Xylene	108-38-3	1.11E-02	SCDM	1.61E+02	SCDM	106.17
m-Cresol	108-39-4	1.82E-04	SCDM	2.27E+04	SCDM	108.14
Toluene	108-88-3	3.74E-02	SCDM	5.26E+02	SCDM	92.14
Chlorobenzene	108-90-7	1.58E-02	SCDM	4.72E+02	SCDM	112.56
Cyclohexanone	108-94-1	5.70E-03	SCDM	5.00E+03	SCDM	98.14
2-Ethoxyethanol	110-80-5	6.99E-03	SCDM	1.00E+06	SCDM	90.12
Pyridine	110-86-1	2.74E-02	SCDM	1.00E+06	SCDM	79.1
Tetrachloroethylene	127-18-4	2.45E-02	SCDM	2.00E+02	SCDM	165.83
Ethyl acetate	141-78-6	1.23E-01	SCDM	8.03E+04	SCDM	88.11
Xylenes (total)	1330-20-7	1.06E-02	SCDM	1.86E+02	SCDM	106.17

Table 4-2. Input Parameters Used in the Landfill Partitioning Model

Parameter	Central Tendency	High End	Source
Annual waste quantity (tonne)	0.078	0.31	Calculated
Lifetime of landfill (yr)	30		US EPA, 1988
Total area of landfill (m ²)	60,705	8,094	US EPA, 1988
Depth of landfill (m)	5.5		Texas Landfill Survey
Bulk density of municipal waste (tonne/m ³)	0.522		US EPA, 1994
Mass of waste/cell (kg)	Calculated		Calculated
Average annual precipitation (cm)	119	75	ISMCS, 1992
Average annual evapotranspiration (cm)	66	47	Leeden, 1990
Average annual runoff (cm)	14	3	Leeden, 1990
Average annual irrigations	0	0	Assumption
Average annual infiltration (cm)	40	25	Calculated
Fraction organic carbon (municipal waste) (g/g)	0.41		US EPA, 1994
Total porosity ^a (municipal waste) (cm ³ /cm ³)	0.67		US EPA, 1994
Liquid filled porosity ^a (municipal waste) (cm ³ /cm ³)	0.12		US EPA, 1994
Air porosity (cm ³ /cm ³)	0.55		Calculated
Depth of daily waste additions (m)	0.76		40 CFR 258
Time uncovered (hr)	12		Assumed
Thickness of daily cover (soil) (m)	0.15		US EPA, 1994
Thickness of cap (clay) (m)	0.60		US EPA, 1994
Operating days/year	350		Assumed
Layers	5.4		Calculated
Daily additions/layer	65		Calculated
Average exposed time (days)	68		Calculated
Area of daily addition (m ²)	47		Calculated

4.2 Air Emissions, Dispersion, and Deposition

The Industrial Source Complex Model Short Term (ISCST3) model was used to model dispersion of the volatile emissions from the landfill to the receptor (U.S. EPA, 1995a). The emissions from all three waste emission processes (uncovered wastepile, daily covered wastepile, and capped cell) are summed and averaged for the entire landfill area for each time step. Table 4-3 presents the estimated air emission rates at each modeled landfill and the corresponding air concentrations of vapors at receptor locations. These averaged total emissions are then modeled using ISCST3. ISCST3 is a Gaussian plume model that can simulate both wet and dry deposition and plume depletion. The model uses annual hourly surface observation meteorologic data and twice daily upper air data. The EPA's ISCST3 model is applicable in simple, intermediate, and complex terrains. However, as discussed in Volume II of the ISCST3 User's Guide (U.S. EPA, 1995a), the complex terrain screening algorithms do not apply to area sources such as the emission source being investigated as part of this analysis (i.e., municipal landfill). Consequently, regardless of the location being modeled, receptor elevations and the terrain grid pathway were not specified in the ISCST3 input files. The ISCST3 model was run using "default" model options specified in the *Guideline on Air Quality Models* (U.S. EPA, 1993). The ISCST3 outputs were used to estimate the vapor air concentrations of constituents at the receptor locations needed to develop risk estimates associated with exposures attributable to vapor emissions from a municipal landfill. ISCST3 is described in greater detail in Appendix B.

The dispersion and deposition modeling is dependent upon the size of the area being modeled as well as the meteorologic data for the landfill location. The size distribution of landfills is presented in Section 3.0. For a previous risk assessment, a representative distribution of landfill cell areas was modeled for all 29 meteorologic locations (RTI, 1998). A sensitivity analysis was conducted to verify that air dispersion modeling results for a landfill cell area in the middle of a specified range of landfill cell areas can be used to represent the results for the range of cell areas. This sensitivity analysis is presented in Appendix C. The representative cell areas used to develop the modeling results used in this risk assessment are presented in Table 4-4.

The dispersion and deposition of vapors also varies with the distances between the landfill and the receptor. The distance to receptor used in this risk analysis is 75 m (U.S. EPA, 1991). A previous sensitivity analysis that examined the issue of the placement of receptors showed that the maximum downwind concentrations decrease sharply from the edge of the source to about 1,000 m from the source (RTI, 1998). After the first 1,000 m from the edge of the area source, concentrations decrease very slowly as downwind distance increases. Therefore, receptor points were placed on 0-, 25-, 50-, 75-, 150-, 500-, and 1,000-m receptor squares starting from the edge of the source, with 16 receptor points on each square. Appendix D presents this sensitivity analysis. For this project, the maximum air concentration of vapors for the receptors at the 75-m distance from the edge of the source were used.

Table 4-3. Air Emission Rates at the Landfill and Corresponding Air Concentration of Vapors at the Receptor Location

	50th Percentile Landfill Area								
		Large Quantity Generator				Small Quantity Generator			
		Lincoln		Houston		Lincoln		Houston	
		Emission Rate	air conc	Emission Rate	air conc	Emission Rate	air conc	Emission Rate	air conc
Constituent	CAS	(g/s-m ²)	(ug/m3)	(g/s-m ²)	(ug/m3)	(g/s-m ²)	(ug/m3)	(g/s-m ²)	(ug/m3)
Carbon tetrachloride	56-23-5	5.05E-08	0.02751	5.05E-08	0.02382	1.27E-08	0.00692	1.27E-08	0.00599
Ethyl ether	60-29-7	5.25E-08	0.02859	5.25E-08	0.02474	1.32E-08	0.00719	1.32E-08	0.00622
Methanol	67-56-1	3.02E-08	0.01648	3.90E-08	0.01842	7.60E-09	0.00414	9.81E-09	0.00463
Acetone	67-64-1	5.94E-08	0.03239	6.25E-08	0.02953	1.49E-08	0.00815	1.57E-08	0.00742
Butanol	71-36-3	1.23E-09	0.00067	1.26E-09	0.00059	3.09E-10	0.00017	3.17E-10	0.00015
Benzene	71-43-2	4.92E-08	0.02680	4.92E-08	0.02320	1.24E-08	0.00674	1.24E-08	0.00583
Trichloroethane, 1,1,1-	71-55-6	5.10E-08	0.02780	5.10E-08	0.02407	1.28E-08	0.00699	1.28E-08	0.00605
Methylene chloride	75-09-2	6.46E-08	0.03521	6.45E-08	0.03041	1.62E-08	0.00885	1.62E-08	0.00765
Carbon disulfide	75-15-0	6.47E-08	0.03524	6.47E-08	0.03051	1.63E-08	0.00886	1.63E-08	0.00767
Trichlorofluoromethane	75-69-4	6.34E-08	0.03458	6.34E-08	0.02994	1.60E-08	0.00869	1.59E-08	0.00753
Dichlorodifluoromethane	75-71-8	5.33E-08	0.02904	5.33E-08	0.02515	1.34E-08	0.00730	1.34E-08	0.00632
Trichloro-1,1,2,2-trifluoroethane, 1,1,2-	76-13-1	6.54E-08	0.03567	6.55E-08	0.03090	1.65E-08	0.00897	1.65E-08	0.00777
Isobutyl alcohol	78-83-1	3.03E-09	0.00165	2.96E-09	0.00139	7.63E-10	0.00042	7.44E-10	0.00035
Methyl ethyl ketone	78-93-3	3.52E-08	0.01918	3.73E-08	0.01759	8.85E-09	0.00482	9.37E-09	0.00442
Trichloroethane, 1,1,2-	79-00-5	1.52E-08	0.00829	1.52E-08	0.00718	3.83E-09	0.00208	3.83E-09	0.00181
Trichloroethylene	79-01-6	3.09E-08	0.01686	3.09E-08	0.01460	7.78E-09	0.00424	7.78E-09	0.00367
Nitropropane, 2- *	79-46-9	2.79E-08	0.01518	2.75E-08	0.01300	7.01E-09	0.00382	6.92E-09	0.00327
o-Xylene	95-47-6	8.61E-09	0.00469	8.69E-09	0.00406	2.16E-09	0.00118	2.18E-09	0.00102
Cresol, o-	95-48-7	6.35E-11	0.00003	6.72E-11	0.00003	1.60E-11	0.00001	1.69E-11	0.00001
Dichlorobenzene, 1,2-	95-50-1	5.42E-10	0.00030	5.42E-10	0.00026	1.36E-10	0.00007	1.36E-10	0.00006
Nitrobenzene	98-95-3	3.28E-10	0.00018	3.30E-10	0.00016	8.24E-11	0.00004	8.29E-11	0.00004
Ethylbenzene	100-41-4	1.13E-08	0.00615	1.13E-08	0.00532	2.84E-09	0.00155	2.85E-09	0.00134
Cresol, p-	106-44-5	5.50E-11	0.00003	6.18E-11	0.00003	1.38E-11	0.00001	1.55E-11	0.00001
Methyl isobutyl ketone	108-10-1	1.57E-08	0.00858	1.57E-08	0.00737	3.96E-09	0.00216	3.95E-09	0.00185
m-Xylene	108-38-3	8.32E-09	0.00453	8.40E-09	0.00393	2.09E-09	0.00114	2.11E-09	0.00099
Cresol, m-	108-39-4	5.59E-11	0.00003	6.46E-11	0.00003	1.41E-11	0.00001	1.62E-11	0.00001
Toluene	108-88-3	2.44E-08	0.01328	2.44E-08	0.01150	6.13E-09	0.00334	6.13E-09	0.00289
Chlorobenzene	108-90-7	9.35E-09	0.00510	9.36E-09	0.00442	2.35E-09	0.00128	2.35E-09	0.00111
Cyclohexanone	108-94-1	1.31E-09	0.00072	1.30E-09	0.00061	3.30E-10	0.00018	3.28E-10	0.00015
Ethoxyethanol, 2- **	110-80-5	1.00E-09	0.00055	2.22E-09	0.00105	2.52E-10	0.00014	5.58E-10	0.00026
Pyridine**	110-86-1	2.65E-09	0.00144	2.68E-09	0.00126	6.67E-10	0.00036	6.74E-10	0.00032
Tetrachloroethylene	127-18-4	4.22E-08	0.02300	4.22E-08	0.01992	1.06E-08	0.00578	1.06E-08	0.00501
Ethyl acetate	141-78-6	3.39E-08	0.01850	3.33E-08	0.01571	8.54E-09	0.00465	8.37E-09	0.00395
Xylenes (total)	1330-20-7	7.21E-09	0.00393	7.23E-09	0.00340	1.81E-09	0.00099	1.82E-09	0.00086

(continued)

Table 4-3. (continued)

		10th Percentile Landfill Area							
		Large Quantity Generator				Small Quantity Generator			
		Lincoln		Houston		Lincoln		Houston	
		Emission Rate	air conc	Emission Rate	air conc	Emission Rate	air conc	Emission Rate	air conc
Constituent	CAS	(g/s-m ²²)	(ug/m3)	(g/s-m ²²)	(ug/m3)	(g/s-m ²²)	(ug/m3)	(g/s-m ²²)	(ug/m3)
Carbon tetrachloride	56-23-5	3.79E-07	0.04759	3.79E-07	0.03857	9.52E-08	0.01197	9.52E-08	0.00970
Ethyl ether	60-29-7	3.95E-07	0.04967	3.94E-07	0.04013	9.94E-08	0.01249	9.91E-08	0.01009
Methanol	67-56-1	2.27E-07	0.02851	2.93E-07	0.02982	5.71E-08	0.00717	7.36E-08	0.00750
Acetone	67-64-1	4.46E-07	0.05605	4.69E-07	0.04781	1.12E-07	0.01409	1.18E-07	0.01202
Butanol	71-36-3	9.49E-09	0.00119	9.46E-09	0.00096	2.39E-09	0.00030	2.38E-09	0.00024
Benzene	71-43-2	3.69E-07	0.04640	3.69E-07	0.03759	9.28E-08	0.01167	9.28E-08	0.00945
Trichloroethane, 1,1,1-	71-55-6	3.83E-07	0.04809	3.83E-07	0.03897	9.62E-08	0.01209	9.62E-08	0.00980
Methylene chloride	75-09-2	4.85E-07	0.06096	4.84E-07	0.04929	1.22E-07	0.01533	1.22E-07	0.01239
Carbon disulfide	75-15-0	4.85E-07	0.06100	4.85E-07	0.04945	1.22E-07	0.01534	1.22E-07	0.01243
Dichlorodifluoromethane	75-71-8	4.00E-07	0.05024	4.00E-07	0.04072	1.01E-07	0.01263	1.01E-07	0.01024
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	4.91E-07	0.06174	4.91E-07	0.05005	1.24E-07	0.01553	1.24E-07	0.01259
Isobutyl alcohol	78-83-1	2.30E-08	0.00289	2.22E-08	0.00226	5.79E-09	0.00073	5.58E-09	0.00057
Methyl ethyl ketone	78-93-3	2.64E-07	0.03319	2.80E-07	0.02849	6.64E-08	0.00834	7.03E-08	0.00716
Trichloroethane, 1,1,2-	79-00-5	1.14E-07	0.01434	1.14E-07	0.01163	2.87E-08	0.00361	2.87E-08	0.00292
Trichloroethylene	79-01-6	2.32E-07	0.02917	2.32E-07	0.02365	5.84E-08	0.00734	5.84E-08	0.00595
Nitropropane, 2- *	79-46-9	2.09E-07	0.02627	2.07E-07	0.02105	5.26E-08	0.00661	5.20E-08	0.00529
o-Xylene	95-47-6	6.52E-08	0.00819	6.52E-08	0.00664	1.64E-08	0.00206	1.64E-08	0.00167
Cresol, o-	95-48-7	4.81E-10	0.00006	5.04E-10	0.00005	1.21E-10	0.00002	1.27E-10	0.00001
Dichlorobenzene, 1,2-	95-50-1	4.07E-09	0.00051	4.07E-09	0.00041	1.02E-09	0.00013	1.02E-09	0.00010
Nitrobenzene	98-95-3	2.46E-09	0.00031	2.47E-09	0.00025	6.18E-10	0.00008	6.22E-10	0.00006
Ethylbenzene	100-41-4	8.51E-08	0.01069	8.50E-08	0.00866	2.14E-08	0.00269	2.14E-08	0.00218
Cresol, p-	106-44-5	4.53E-10	0.00006	4.64E-10	0.00005	1.14E-10	0.00001	1.17E-10	0.00001
Methyl isobutyl ketone	108-10-1	1.19E-07	0.01497	1.18E-07	0.01202	3.00E-08	0.00376	2.97E-08	0.00302
m-Xylene	108-38-3	6.30E-08	0.00792	6.30E-08	0.00642	1.59E-08	0.00199	1.58E-08	0.00161
Toluene	108-88-3	1.83E-07	0.02300	1.83E-07	0.01865	4.60E-08	0.00578	4.60E-08	0.00469
Chlorobenzene	108-90-7	7.02E-08	0.00882	7.02E-08	0.00715	1.77E-08	0.00222	1.77E-08	0.00180
Cyclohexanone	108-94-1	1.02E-08	0.00128	9.79E-09	0.00100	2.57E-09	0.00032	2.46E-09	0.00025
Ethoxyethanol, 2- **	110-80-5	7.52E-09	0.00095	1.67E-08	0.00170	1.89E-09	0.00024	4.19E-09	0.00043
Pyridine**	110-86-1	2.00E-08	0.00252	2.01E-08	0.00205	5.03E-09	0.00063	5.05E-09	0.00051
Tetrachloroethylene	127-18-4	3.17E-07	0.03979	3.17E-07	0.03225	7.96E-08	0.01001	7.96E-08	0.00811
Ethyl acetate	141-78-6	2.55E-07	0.03205	2.50E-07	0.02545	6.41E-08	0.00806	6.28E-08	0.00640
Xylenes (total)	1330-20-7	5.42E-08	0.00682	5.42E-08	0.00553	1.36E-08	0.00171	1.36E-08	0.00139

Table 4-4. Landfill Areas

10th Percentile size	8,094 m ²
50th Percentile size	60,705 m ²

Source: U.S. EPA, 1988.

In addition, a second scenario has been modeled assuming that daily cover has been applied after 6 hours instead of the initial assumption of 12 hours. No appreciable change in risk was observed.

Table 4-5 presents data for the relative quantity of mass volatilized 1) from uncovered waste, 2) through the daily cover, and 3) from the capped cell for an example solvent (xylene). This comparison demonstrates that the overwhelming proportion of the volatile emissions occur after application of the daily soil cover and prior to application of the cell cap. For this reason the length of time the waste is uncovered makes very little difference to the total annual mass of solvent released into the air and, thus, has little effect on the risk or hazard quotient due to inhalation of volatiles emitted from the landfill. This is due to the fact that waste is uncovered for only 12 hours and covered for many days/months/years before CAP applied? The trend shown for in this table is valid for all other solvent constituents, although the exact values may vary somewhat from those presented for xylene.

Table 4-5. Comparison of the Total Mass of Xylene Volatilized: from Uncovered Waste, Through Daily Cover, and from Capped Cells Over the Maximum Exposure Duration

			Capped Cells (mg)/ %	
12 hours	5,999 0.04%	13,610,467 99.74%	29,130.21 0.21%	13,645,596
6 hours	4,242 0.03%	13,018,970 99.74%	29,189.96 0.22%	13,052,402
Difference	1,757	591,496	-59.8	593,194

4.3 Leaching

The partitioning model described in Section 4.1 estimates leachate concentrations over time as well as air emissions. In order to be more realistic and to maintain a mass balance within the landfill, all loss mechanisms are included in the partitioning model. These losses include air emissions, degradation, and leaching. Leaching is assumed to continue from all cells that contain waste, even after a cell is capped and the landfill is closed. In fact, maximum leachate concentrations occur after landfill closure.

The modeled landfill is a Subtitle D municipal landfill that has an earthen cover but no liner or leachate collection system. The leachate flux through the landfill is the result of infiltration of ambient precipitation through the landfill cover. For the groundwater pathway analysis, it is assumed that the landfill has a 30-year operational life. The total amount of constituent in the landfill available for leaching is the product of annual waste quantity and the net postvolatilization and degradation constituent concentration in the waste times 30 years. The 30-year time frame is based on the average active lifetime of Municipal Subtitle D landfills (U.S. EPA, 1988).

The loss of a contaminant due to leaching is estimated by assuming the leachate is in equilibrium with the waste in the landfill. The leachate concentration is calculated in time steps over the life of the landfill and for 40 years after closure. A mass balance is maintained in the landfill over time. The highest 9-year average constituent concentrations estimated in the leachate are used to calculate the concentrations expected at the groundwater well location. The leachate concentrations from landfills remain virtually constant although the maximum value varies from the 9-year average by a maximum factor of 1.11. This difference is small in this analysis and has not been considered.

First-order degradation rates (and hydrolysis rates, if applicable) are input to the model from reported literature values or calculated from reported contaminant half-lives. In this case, the lowest reported contaminant half-lives in soil identified in the literature (Howard et al., 1991) have been used to calculate an apparent first-order disappearance rate. The overall apparent first-order disappearance rate is simply the sum of all of the individual first-order rate constants. In this model, all other losses (volatilization and leaching) are subtracted from this overall first-order disappearance rate and the remaining portion is assumed to be biodegradation. Thus, losses due to biodegradation are also included in the mass balance of the landfill system. These half-lives and the resulting first-order degradation rates for solvent constituents are presented in Table 4-6.

To estimate the concentrations of constituents of potential concern at the location of the residential drinking water well without performing constituent-specific modeling, a simplistic approach from the *Determination of Groundwater Dilution Attenuation Factors for Fixed Waste Site Areas Using EPACMTP* (U.S. EPA, 1995b) was used to estimate dilution of the leachate before it reaches the residential well. For this particular analysis, an EPACMTP analysis that developed DAFs for use in the Soil Screening Guidance was used to provide "readily available" DAFs as a function of landfill size. This analysis is documented in Appendix D. The Monte Carlo analysis provided a distribution of DAFs for several landfill size ranges. The results that are most appropriate for this analysis are found in Table A-2 (page E-56) of Appendix D and are displayed graphically in Figure 6 on page E-42 of Appendix D.

These results were developed through Monte Carlo model runs using a nationwide distribution of aquifer characteristics and well locations and depths (x- and z-coordinates) from Agency surveys on the distance of residential wells from municipal landfills and data on the depth of residential drinking water wells, respectively. The horizontal well position (y-coordinate) is determined so that the well location falls within the approximate areal extent of the contaminant plume. The DAFs selected from these runs were used to estimate the leachate

Table 4-6. Soil Degradation Rates

Compound	CAS	Half-life (yr)	Soil degradation rate (1/yr)
Carbon tetrachloride	56-23-5	7.0E-01	9.9E-01
Ethyl ether	60-29-7	NA	NA
Methanol	67-56-1	3.6E+01	1.9E-02
Acetone	67-64-1	3.6E+01	1.9E-02
Butanol	71-36-3	3.6E+01	1.9E-02
Benzene	71-43-2	1.6E+01	4.4E-02
1,1,1-Trichloroethane	71-55-6	9.3E-01	7.5E-01
Methylene chloride	75-09-2	9.0E+00	7.7E-02
Carbon disulfide	75-15-0	NA	NA
Trichlorofluoromethane	75-69-4	7.0E-01	9.9E-01
1,1,2-Trichloro-1,2,2-trifluoroethane	75-71-8	NA	NA
Isobutyl alcohol	76-13-1	3.6E+01	1.9E-02
Methyl ethyl ketone	78-83-1	3.6E+01	1.9E-02
1,1,2-Trichloroethane	78-93-3	6.9E-01	1.0E+00
Trichloroethylene	79-00-5	7.0E-01	9.9E-01
2-Nitropropane	79-01-6	1.4E+00	4.9E-01
<i>o</i> -Xylene	79-46-9	NA	NA
<i>o</i> -Cresol	95-47-6	8.7E+00	7.9E-02
1,2-Dichlorobenzene	95-48-7	1.4E+00	4.9E-01
Nitrobenzene	95-50-1	1.3E+00	5.4E-01
Ethylbenzene	98-95-3	2.5E+01	2.7E-02
<i>p</i> -Cresol	100-41-4	3.8E+02	1.8E-03
Methyl isobutyl ketone	106-44-5	3.6E+01	1.9E-02
<i>m</i> -Xylene	108-10-1	NA	NA
<i>m</i> -Cresol	108-38-3	3.6E+01	1.9E-02
Toluene	108-39-4	1.1E+01	6.0E-02
Chlorobenzene	108-88-3	1.7E+00	4.1E-01
Cyclohexanone	108-90-7	NA	NA
2-Ethoxyethanol	108-94-1	9.0E+00	7.7E-02
Pyridine	110-80-5	3.6E+01	1.9E-02
Tetrachloroethylene	110-86-1	7.0E-01	9.9E-01
Ethyl acetate	127-18-4	3.6E+01	1.9E-02
Cresylic acid	141-78-6	NA	NA
Xylenes (total)	1330-20-7	9.0E+00	7.7E-02

NA = Not available.

concentration. The other parameter influencing this analysis is the surface area of the landfill. The larger the landfill area, the lower the DAF. These factors are discussed in Section 3.3.

In developing these DAFs the source area was set to a different but constant value in each run, the distance to the receptor well was set at a nationwide distribution, and all other parameters were varied in the Monte Carlo analysis. These variables are presented in Table 3 (page E-28) of Appendix D. Appendix D describes the methodology used to determine these values. The DAFs selected for use in this analysis are presented in Table 4-6. This methodology provides a reasonable screening mechanism for potential releases from an unlined municipal landfill. These results do not include any leachate collection or landfill liner systems. The resulting contaminant concentration in the leachate and the corresponding residential wells are presented in Table 4-7. If a more realistic risk from the groundwater pathway is desired, a comprehensive EPACMTP analysis will be required.

In this analysis a clay liner and associated leachate collection system that meets the regulatory requirements of 40 CFR § 258.40 for design criteria for municipal landfills. These criteria include:

(2) With a composite liner, as defined in paragraph (b) of this section and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

(b) For purposes of this section, composite liner means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

The regulations presented above, also call for a FML that is at least 30 -mil thick or for those made of high density polyethylene (HDPE) that is at least 60-mil thick, however, at this time modeling parameters for FMLs over time have not been established. If this liner is assumed to remain intact for 10,000 years, infiltration would be reduced to near zero. However, this is not to the case. Some leaks are known to be present initially from seam imperfections and others develop over time, however, no method has been developed to model leaking liners. Therefore, the case that is modeled here is for a municipal landfill with 2-foot clay liner installed with a leachate collection system that maintains a 30 cm depth of leachate over the liner. This is a bounding liner condition. In actual practice there will be a FML installed in contact with the clay liner (which may be thicker than 2 feet) and the leachate collection system will most likely keep the depth of the leachate over the liner to less than 30 cm.

**Table 4-7. Dilution/Attenuation Factors (DAFs),
95th Percentile (Nationwide distribution of x-well)**

Landfill	Area (m ²)	DAF (unitless)
Central tendency	60,705	11
Small	12,141	27

Source: U.S. EPA, 1995b. Attachment E.

The landfill partitioning model used to estimate emissions and leachate from the landfill has been modified to include these liner requirements. Equations have been added to estimate the amount of leachate that would be needed to saturate the liner and the volume of leachate that would pass through the clay liner once the liner has been saturated. It is assumed that the remaining liquid collects over the liner to a depth of 30 cm and any excess leachate is discharged through the leachate collection system. The fraction of organic carbon of the clay liner is assumed to be very low (HELP model), therefore, only an exceedingly small fraction of the solvent constituents are adsorbed by the liner. Liner parameters used in the model are presented in Table 4-8

The addition of the liner does not change the quality or quantity of the potential leachate generated in the landfill. It only restricts the volume of infiltration that may be released from the landfill to the groundwater. The reduction in the constituent concentration in the groundwater is, thus, directly proportional the reduction in the volume of leachate by the liner. The infiltration rate without the liner is dependent only upon the climate conditions that are associated with the selected geographical locations. The infiltration rate with the liner and leachate collection system in place is dependent only upon design criteria (hydraulic conductivity of the liner and allowable depth of leachate over the liner) of the system. Therefore, the infiltration rate with identical liner systems is identical regardless of their geographical location. The infiltration rates for each site both with and without the clay liner and leachate collection system described above are presented in Table 4-9.

Table 4-8. Liner Parameters Used in Analysis

Liner Parameters	Units	Value	Reference
Depth of Liner	cm	60.96	40CFR §258.40
Sat. hydraulic conductivity	cm/s	1E-07	40CFR §258.40
Sat. hydraulic conductivity	cm/yr	3.15	Calculated
liner parameter alpha	1/cm	0.008	U.S. EPA, 1994
liner parameter beta		1.09	U.S. EPA, 1994
bulk density of liner	g/cm ³	1.80	U.S. EPA, 1994
total porosity	unitless	0.25	U.S. EPA, 1994
fraction organic carbon	unitless	0.00667	U.S. EPA, 1994
depth of leachate over liner	cm	30	40CFR §258.40

Table 4-9. Infiltration Rates for Landfills With and Without a Liner and Leachate Collection System

Location	Without Liner (cm/yr)	With Liner and Leachate Collection (cm/yr)	Ratio of Infiltration Rates
Lincoln, NE	24.9	4.7	0.19
Houston, TX	39.7	4.7	0.12

5.0 Receptors and Exposure Pathways

Receptors, for this analysis, are defined as individuals who may be exposed to constituents released from a municipal landfill. Exposure pathway is a broad term that encompasses the source, release and transport mechanism(s), exposure points, and exposure routes (inhalation, ingestion, or dermal contact) and describes where, when, and how a receptor is exposed. This section discusses the receptors and exposure pathways identified in the conceptual site exposure model (CSEM) (Figure 5-1).

5.1 Receptors

Receptors evaluated in this risk assessment were selected to defined receptor as an individual with typical or more probable exposures and individuals with higher exposure potential, including sensitive individuals. The latter are included to ensure that both sensitive subpopulations and highly exposed individuals are protected. The receptors selected were an adult farmer and children.

5.1.1 Exposure Pathways

Exposure pathways are described as direct (direct contact with the contaminated source or media) or indirect (contact with a secondary defined receptor as an individual source exposed through contact with contaminated media). This risk assessment includes both direct and indirect exposure pathways.

Constituents associated with contaminated shop towels and wipers managed in offsite municipal landfills could be released as vapors to the air or leach to groundwater (Figure 5-1). It is assumed that erosion and runoff from an operating municipal landfill will be controlled and that daily cover restricts particulate emissions.

An adult farmer or child resident living near the landfill could be exposed to contaminants by inhaling airborne constituents transported offsite as vapors; ingesting constituents in groundwater from a drinking water well; or inhaling, or absorbing through the skin, constituents during household uses of well water (e.g., showering). The model used to evaluate exposure to groundwater contaminants via showering is described in Appendix D.

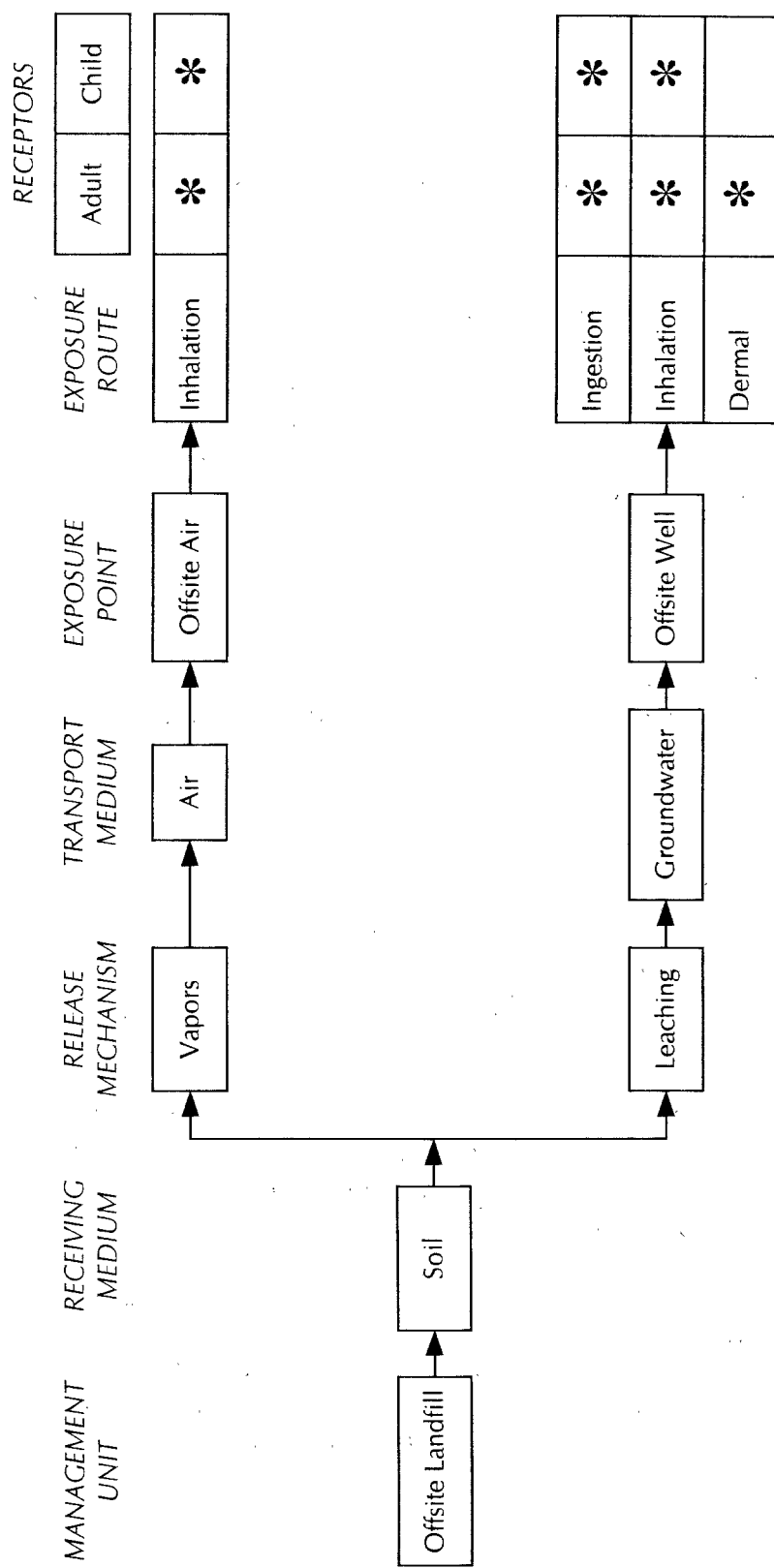


Figure 5-1. Conceptual site exposure model, human health, offsite landfill waste management unit.

5.2 Exposure Durations and Intake Factors

Exposure duration and intake factors are taken from the *Exposure Factor's Handbook* (U.S. EPA, 1997b). Mean or 50th percentile values were used to represent central tendency estimates, and recommended high-end values were used in most cases to represent high-end exposure estimates.

5.2.1 Exposure Duration

Exposure duration refers to the number of years that a receptor is exposed to a contaminated source and is assumed to correspond to the receptor's residence time in the same dwelling. The *Exposure Factors Handbook* includes descriptive statistics for residence time for a number of population categories including all households, renters, owners, farms, urban, rural, age, and region of the country. Exposure durations used in this risk assessment are shown in Table 5-1. Residence times of 10 years (50th percentile) were used for the adult farmer as recommended by EPA. The adult farmer exposure duration was chosen because it represents a conservative estimate. Residence times for the child (7.3 years) were based on averaging 50th percentile values reported for children at ages 3, 6, 9, 12, 15, and 18. Exposure duration is only a

Table 5-1. Exposure Durations

	Exposure duration (yr)	Reference
Farmer	10	U.S. EPA, 1997b. Table 15-164.
Child of farmer	7.3	U.S. EPA, 1997b. Table 15-168.

Source: U.S. EPA, 1997b. Table 15-164 "Total Residence Time, t (years), Corresponding to Selected Values of R(t) by Housing Category" for the farmer; Table 15-168 "Descriptive Statistics for Both Genders by Current Age" for the child of farmer.

factor in the estimation of excess cancer risk from constituents because risk is based on the average lifetime daily exposure. Exposure duration is not a factor for noncarcinogenic constituents because the hazard quotient (HQ) is based on the average daily dose during exposure. The baseline risk results presented in this section are based on central tendency exposure duration.

5.3 Air Pathway

5.3.1 Inhalation Rates

Recommended inhalation values in the *Exposure Factors Handbook* are reported by age, sex, activity pattern, and outdoor workers; however, high-end values are lacking in most cases. The recommended values in the *Exposure Factors Handbook* are presented in Table 5-2. Inlet inhalation this analysis we used the inhalation rate for children ages 1-3.

Table 5-2. Summary of Recommended Values for Inhalation

Population	Mean long-term exposures (m ³ /d)
Infants	
<1 yr	4.5
Children	
1-2 yr	6.8
3-5 yr	8.3
6-8 yr	10
9-11 yr	
Males	14
Females	13
12-14 yr	
Males	15
Females	12
15-18 yr	
Males	17
Females	12
Adults (19-65+ yr)	
Males	15.2
Females	11.3

Based on the key study results (i.e., Layton, 1993).

The values in bold are the values used in the analysis

Inhalation risks are based on the most conservative receptors as defined by dose. Dose is defined as the intake of contaminant per unit body weight. Based on dose, the most conservative adult farmer receptor is assumed to be a male 19 to 65+ years (body weight = 70 kg) and the most conservative child receptor is assumed to be a 0- to 5-year-old (body weight = 14 kg).

5.4 Groundwater Pathways

Groundwater exposure pathways include groundwater ingestion, inhalation of vapors from household water use, and dermal contact during showering and bathing. This section presents the exposure assumptions.

5.4.1 Ingestion of Contaminated Groundwater

The exposure factors used in the ingestion pathway for contaminated groundwater (Table 5-3) are also recommended values from the *Exposure Factors Handbook* for the adult farmer and child. Table 5-3 presents the drinking water intake rates assumed for the risk assessment.

Table 5-3. Summary of Recommended Drinking Water Intake Rates

Age group	Mean	50th Percentile	90th Percentile	95th Percentile
<1	0.30	0.24	0.65	0.76
<3	0.61	NA	1.5	NA
3-5	0.87	NA	1.5	NA
1-10	0.74	0.66	1.3	1.5
11-19	0.97	0.87	1.7	2.0
Adults	1.4	1.3	2.3	NA
Pregnant women	1.2	1.1	2.2	2.4
Lactating women	1.3	1.3	1.9	2.2

NA = Not available.

The values in bold are the values used in the analysis

Source: U.S. EPA, 1997a.

5.4.2 Noningestion Exposure to Contaminated Groundwater

Noningestion exposures to contaminated groundwater are due to inhalation and dermal exposures from household use of tap water. The greatest source of this exposure is bathing and showering. Additional household tap water use is also considered in this risk assessment. The assumptions used for nongroundwater risk are presented in Table 5-4. In addition to the exposure factors presented in Table 5-4 the health benchmark values used for dermal exposures have been calculated based on values available for oral reference dose (RfD) benchmarks. The dermal permeability and absorption factors used to estimate benchmark values are presented in Table 5-5. Dermal exposures are estimated only for adults. Data for estimating risks to children are not readily available. Appendix E presents the complete documentation of this model.

Table 5-4. Exposure Factors Used to Determine Hazard Quotient from Inhalation Exposure to Contaminated Tap Water

Exposure factor	Parameter value	Reference
Shower duration	10 min	U.S. EPA, 1997b (Table 15-20) (Represents time spent showering only)
Time in bathroom (includes shower duration, time spent in shower stall after showering, and time spent in bathroom after leaving shower stall)	40 min	U.S. EPA, 1997b (Tables 15-20, 15-23, and 15-114) (Table 15-114 represents 24-hour cumulative time spent in bathroom, which is conservative to assume that all of this time occurs immediately following the shower)
Shower rate	5.5 L/min	Calculated (based on drop diameter and nozzle velocity)
Shower/bath water use	15 gallons per capita per day (gcd)	U.S. EPA, 1997b (Table 17-14) (Median value across several studies)
Bathroom water use	35.5 gcd	U.S. EPA, 1997b (Table 17-14) (Summation of median values for <i>shower</i> , <i>toilet</i> , and one-half of the <i>other</i> water use rates; RTI assumed <i>other</i> represents water use in sinks)
House water use	17.5 gcd	U.S. EPA, 1997b (Table 17-14) (Summation of median values for <i>Laundry</i> , <i>Dishwashing</i> , and one-half of the <i>other</i> water use rates; RTI assumed <i>other</i> represents water use in sinks)
Volume of shower stall	2 m ³	McKone, 1987
Volume of bathroom	10 m ³	McKone, 1987
Volume of house	369 m ³	U.S. EPA, 1997b (Table 17-31)
Volumetric gas exchange rate between shower and bathroom	100 L/min	RTI-derived value
Volumetric gas exchange rate between bathroom and house	300 L/min	RTI-derived value
Volumetric gas exchange rate between house and atmosphere	0.45 air changes per hour (2,768 L/min)	U.S. EPA, 1997b (Table 17-31) (Median value; given a low overall confidence rating)
Fraction emitted, bathroom	0.50	Calculated
Fraction emitted, house water	0.66	Calculated
Time toilet emits	40 min/d	U.S. EPA, 1997b (Tables 15-20, 15-23, and 15-114) (Table 15-114 represents 24 hour-cumulative time spent in bathroom, which is conservative to assume that all of this time occurs immediately following the shower)
Time house water emits	15.7 h/d	U.S. EPA, 1997b (based on cumulative time spent indoors at a residence, Table 15-131, minus time spent in bathroom [see above])

Table 5-5. Permeability Constants and Adsorption Factors for Groundwater Constituents of Potential Concern

Compound	CAS No.	Skin permeability const for water (cm/h)	Bunge constant	Lag Time (h)	Time to steady-state flux (h)	Oral absorption efficiency	Dermal absorption fraction (soil)
Carbon tetrachloride	56-23-5	1.9E-02	5.4E-02	7.6E-01	1.8E+00	0.8	NA
Ethyl ether	60-29-7	2.6E-03	6.8E-04	2.5E-01	5.9E-01	0.8	NA
Methanol	67-56-1	3.8E-04	1.9E-05	1.4E-01	3.3E-01	0.8	NA
Acetone	67-64-1	5.7E-04	5.8E-05	2.0E-01	4.7E-01	0.8	NA
Butanol	71-36-3	2.7E-03	7.1E-04	2.5E-01	5.9E-01	0.8	NA
Benzene	71-43-2	2.1E-02	1.3E-02	2.6E-01	6.3E-01	0.8	NA
1,1,1-Trichloroethane	71-55-6	1.7E-02	3.0E-02	5.7E-01	1.4E+00	0.8	NA
Methylene chloride	75-09-2	4.5E-03	1.8E-03	2.9E-01	6.9E-01	0.8	NA
Carbon disulfide	75-15-0	1.7E-02	1.0E-02	2.5E-01	6.1E-01	0.8	NA
Trichlorofluoromethane	75-69-4	1.7E-02	3.4E-02	6.0E-01	1.4E+00	0.8	NA
Dichlorodifluoromethane	75-71-8	1.2E-02	1.4E-02	4.8E-01	1.1E+00	0.8	NA
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	2.4E-02	1.4E-01	1.2E+00	4.1E+00	0.8	NA
Isobutyl alcohol	78-83-1	2.3E-03	5.6E-04	2.5E-01	5.9E-01	0.8	NA
Methyl ethyl ketone	78-93-3	1.1E-03	1.9E-04	2.4E-01	5.8E-01	0.8	NA
1,1,2-Trichloroethane	79-00-5	8.4E-03	1.1E-02	5.7E-01	1.4E+00	0.8	NA
Trichloroethylene	79-01-6	2.5E-02	5.1E-02	5.5E-01	1.3E+00	0.8	NA
2-Nitropropane	79-46-9	2.3E-03	7.4E-04	3.1E-01	7.3E-01	0.8	NA
o-Xylene	95-47-6	7.2E-02	1.3E-01	3.9E-01	1.2E+00	0.8	NA
o-Cresol	95-48-7	1.1E-02	9.8E-03	4.0E-01	9.6E-01	0.5	NA
1,2-Dichlorobenzene	95-50-1	6.6E-02	2.7E-01	6.9E-01	3.4E+00	0.8	NA
Nitrobenzene	98-95-3	6.8E-03	6.9E-03	4.9E-01	1.2E+00	0.8	NA
Ethylbenzene	100-41-4	7.3E-02	1.4E-01	3.9E-01	1.3E+00	0.8	NA
p-Cresol	106-44-5	1.0E-02	8.9E-03	4.0E-01	9.6E-01	0.5	NA
Methyl isobutyl ketone	108-10-1	3.3E-03	1.5E-03	3.6E-01	8.6E-01	0.8	NA
m-Xylene	108-38-3	8.0E-02	1.6E-01	3.9E-01	1.4E+00	0.8	NA
m-Cresol	108-39-4	1.0E-02	9.3E-03	4.0E-01	9.6E-01	0.5	NA
Toluene	108-88-3	4.7E-02	5.6E-02	3.2E-01	7.7E-01	0.8	NA
Chlorobenzene	108-90-7	4.2E-02	7.2E-02	4.3E-01	1.0E+00	0.8	NA
Cyclohexanone	108-94-1	1.8E-03	6.5E-04	3.5E-01	8.3E-01	0.5	NA
2-Ethoxyethanol	110-80-5	4.6E-04	7.9E-05	3.1E-01	7.4E-01	0.8	NA
Pyridine	110-86-1	1.9E-03	4.7E-04	2.7E-01	6.4E-01	0.8	NA
Tetrachloroethylene	127-18-4	1.5E-02	4.7E-02	9.0E-01	2.2E+00	0.8	NA
Ethyl acetate	141-78-6	1.7E-03	4.9E-04	3.0E-01	7.2E-01	0.8	NA
Xylenes (total)	1330-20-7	7.6E-02	1.5E-01	3.9E-01	1.3E+00	0.8	NA

6.0 Risk Results

The risk results presented in this section are for a single facility disposing of contaminated shop towels and wipers in a municipal landfill. All wipers are assumed to weigh an equal amount and to be contaminated with an equal amount of solvent. This section also discusses use of these results for other possible disposal scenarios. Risk assessment results are presented separately for the air pathway and the groundwater pathway. Benchmarks used to generate hazard quotients for noncarcinogens and risk estimates for carcinogens are presented in Table 6-1.

6.1 Air Pathway Results

The air pathway in this analysis is limited to the inhalation of vapors. Risk assessment results for the adult and child receptor are presented for each size of landfill (small and central tendency) and each size of generator (small and large quantity) for each location (Houston, Texas, and Lincoln, Nebraska).

The inhalation risk results are estimated for all combinations of the following:

- Adults and children
- Locations (Houston or Lincoln)
- Landfill sizes (central tendency and small)
- Generator sizes (SQG and LQG)
- Duration daily waste addition is uncovered (6 hr or 12 hr).

The inhalation risk results are presented in Tables 6-3 through 6-10. The estimated risks are presented for each solvent individually in descending order of risk and are derived assuming that each facility uses one solvent type exclusively. Inhalation hazard quotients are reported for noncarcinogens (Tables 6-3a through 6-10a), and inhalation risk is reported for carcinogens (Tables 6-3b through 6-10b). Results are presented only for receptors 75 m from the edge of the landfill.

6.2 Groundwater Pathway Results

The groundwater risk results are presented in Tables 6-11 through 6-18. The risk estimates are presented for each solvent in descending order of risk and are derived assuming that each facility uses only one type of solvent. Ingestion hazard quotients are reported for noncarcinogens (Tables 6-11a through 6-18a), and ingestion risk is reported for carcinogens (Tables 6-11b through 6-18b). Results are presented for receptor wells 25 feet from the edge of the

landfill, at a national average closest receptor distance, and with a clay liner and leachate collection system for the national average receptor distance.

The exposure factors used in estimating the inhalation and groundwater risk results for the farmer and child are presented in Table 6-2. The air emission rates from the landfills and the air concentrations at the receptor locations used in the risk calculations are presented in Section 4.0, Table 4-3. The leachate concentrations, DAFs and resulting residential well concentrations are presented in Section 4.0, Table 4-7.

The risks for the noningestion pathways have been calculated using a unit concentration for the constituent concentration in groundwater. This allows for the development of risk factors for each segment of the groundwater risk individually. Thus the total risk due to groundwater may be calculated by applying these factors to each segment of the risk. Because the risks are additive and are of similar magnitude, an overall risk factor cannot be developed. The appropriate risk factors are presented for each constituent in Table 6-19. These risk factors should be applied to the groundwater concentrations presented in Section 4.0 Table 4-7 to estimate the noningestion risk for each segment and exposure scenario.

Table 6-1. Benchmarks

Compound	CAS	RfD (mg/kg/d)	RfD source	Oral CSF (mg/kg/d) ⁻¹	Oral CSF source
Carbon tetrachloride	56-23-5	7.00E-04	U.S. EPA, 1998a	1.30E-01	U.S. EPA, 1998a
Ethyl ether	60-29-7	2.00E-01	U.S. EPA, 1998a	NA	NA
Methanol	67-56-1	5.00E-01	U.S. EPA, 1998a	NA	NA
Acetone	67-64-1	1.00E-01	U.S. EPA, 1998a	NA	NA
Butanol	71-36-3	1.00E-01	U.S. EPA, 1998a	NA	NA
Benzene	71-43-2	NA	NA	2.90E-02	U.S. EPA, 1998a
1,1,1-Trichloroethane	71-55-6	2.00E-01	U.S. EPA, 1998b	NA	NA
Methylene chloride	75-09-2	6.00E-02	U.S. EPA, 1998a	7.50E-03	U.S. EPA, 1998a
Carbon disulfide	75-15-0	1.00E-01	U.S. EPA, 1998a	NA	NA
Trichlorofluoromethane	75-69-4	3.00E-01	U.S. EPA, 1998a	NA	NA
Dichlorodifluoromethane	75-71-8	2.00E-01	U.S. EPA, 1998a	NA	NA
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	3.00E+01	U.S. EPA, 1998a	NA	NA
Isobutyl alcohol	78-83-1	3.00E-01	U.S. EPA, 1998a	NA	NA
Methyl ethyl ketone	78-93-3	6.00E-01	U.S. EPA, 1998a	NA	NA
1,1,2-Trichloroethane	79-00-5	4.00E-03	U.S. EPA, 1998a	5.70E-02	U.S. EPA, 1998a
Trichloroethylene	79-01-6	NA	NA	1.10E-02	U.S. EPA, 1998b
2-Nitropropane	79-46-9	NA	NA	NA	NA
o-Xylene	95-47-6	2.00E+00	U.S. EPA, 1997c	NA	NA
o-Cresol	95-48-7	5.00E-02	U.S. EPA, 1998a	NA	NA
1,2-Dichlorobenzene	95-50-1	9.00E-02	U.S. EPA, 1998a	NA	NA
Nitrobenzene	98-95-3	5.00E-04	U.S. EPA, 1998a	NA	NA
Ethylbenzene	100-41-4	1.00E-01	U.S. EPA, 1998a	NA	NA
p-Cresol	106-44-5	5.00E-03	U.S. EPA, 1997c	NA	NA
Methyl isobutyl ketone	108-10-1	8.00E-02	U.S. EPA, 1997c	NA	NA
m-Xylene	108-38-3	2.00E+00	U.S. EPA, 1997c	NA	NA
m-Cresol	108-39-4	5.00E-02	U.S. EPA, 1998a	NA	NA
Toluene	108-88-3	2.00E-01	U.S. EPA, 1998a	NA	NA
Chlorobenzene	108-90-7	2.00E-02	U.S. EPA, 1998a	NA	NA
Cyclohexanone	108-94-1	5.00E+00	U.S. EPA, 1998a	NA	NA
2-Ethoxyethanol	110-80-5	4.00E-01	U.S. EPA, 1998a	NA	NA
Pyridine	110-86-1	1.00E-03	U.S. EPA, 1998a	NA	NA
Tetrachloroethylene	127-18-4	1.00E-02	U.S. EPA, 1998a	NA	NA
Ethyl acetate	141-78-6	9.00E-01	U.S. EPA, 1998a	NA	NA
Xylenes (total)	1330-20-7	2.00E+00	U.S. EPA, 1998a	NA	NA

(continued)

**Table 6-3a. Inhalation Hazard Quotient for Central Tendency Landfill Area
(Large Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.0002	0.0002	0.0002	0.0002
Pyridine	110-86-1	0.0002	0.0002	0.0002	0.0002
Dichlorodifluoromethane	75-71-8	0.0001	0.0001	0.0001	0.0001
Methyl isobutyl ketone	108-10-1	0.00009	0.00009	0.00009	0.00009
Tetrachloroethylene	127-18-4	0.00007	0.00007	0.00007	0.00007
Nitrobenzene	98-95-3	0.00005	0.00005	0.00008	0.00008
Carbon disulfide	75-15-0	0.00004	0.00004	0.00004	0.00004
Trichlorofluoromethane	75-69-4	0.00004	0.00004	0.00004	0.00004
Toluene	108-88-3	0.00003	0.00003	0.00003	0.00003
Trichloroethane, 1,1,1-	71-55-6	0.00002	0.00002	0.00002	0.00002
Methyl ethyl ketone	78-93-3	0.00002	0.00002	0.00002	0.00002
Xylenes (total)	1330-20-7	0.00001	0.00001	0.00001	0.00001
Ethylbenzene	100-41-4	0.000005	0.000005	0.000005	0.000005
Ethoxyethanol, 2-	110-80-5	0.000005	0.000005	0.000005	0.000005
Methanol	67-56-1	0.000001	0.000001	0.000001	0.000001
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000001	0.000001	0.000001	0.000001
Dichlorobenzene, 1,2-	95-50-1	0.000001	0.000001	0.000001	0.000001
Acetone	67-64-1	0.0000009	0.0000009	0.000001	0.000001
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available

**Table 6-3b. Inhalation Risk for Central Tendency Landfill Area
(Large Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2- A19	79-46-9	3.6E-06	5.6E-06	3.7E-06	5.7E-06
Carbon tetrachloride	56-23-5	3.7E-08	5.7E-08	3.7E-08	5.8E-08
Benzene	71-43-2	2.0E-08	3.1E-08	2.0E-08	3.1E-08
Trichloroethane, 1,1,2-	79-00-5	1.2E-08	1.8E-08	1.2E-08	1.9E-08
Trichloroethylene	79-01-6	2.5E-09	3.9E-09	2.6E-09	4.0E-09
Methylene chloride	75-09-2	1.5E-09	2.3E-09	1.5E-09	2.3E-09

**Table 6-4a. Inhalation Hazard Quotient for Central Tendency Landfill Area
(Large Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.0002	0.0002	0.0003	0.0003
Pyridine	110-86-1	0.0002	0.0002	0.0002	0.0002
Dichlorodifluoromethane	75-71-8	0.0001	0.0001	0.0001	0.0001
Methyl isobutyl ketone	108-10-1	0.0001	0.0001	0.0001	0.0001
Tetrachloroethylene	127-18-4	0.00008	0.00008	0.00008	0.00008
Nitrobenzene	98-95-3	0.00006	0.00006	0.00009	0.00009
Carbon disulfide	75-15-0	0.00005	0.00005	0.00005	0.00005
Trichlorofluoromethane	75-69-4	0.00005	0.00005	0.00005	0.00005
Toluene	108-88-3	0.00003	0.00003	0.00003	0.00003
Trichloroethane, 1,1,1-	71-55-6	0.00003	0.00003	0.00003	0.00003
Methyl ethyl ketone	78-93-3	0.00002	0.00002	0.00002	0.00002
Xylenes (total)	1330-20-7	0.00001	0.00001	0.00001	0.00001
Ethylbenzene	100-41-4	0.000006	0.000006	0.000006	0.000006
Ethoxyethanol, 2-	110-80-5	0.000003	0.000003	0.000003	0.000003
Methanol	67-56-1	0.000001	0.000001	0.000001	0.000001
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000001	0.000001	0.000001	0.000001
Dichlorobenzene, 1,2-	95-50-1	0.000001	0.000001	0.000001	0.000001
Acetone	67-64-1	0.000001	0.000001	0.000001	0.000001
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not Available.

**Table 6-4b. Inhalation Risk for Central Tendency Landfill Area
(Large Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	4.2E-06	6.5E-06	4.3E-06	6.6E-06
Carbon tetrachloride	56-23-5	4.2E-08	6.6E-08	4.3E-08	6.7E-08
Benzene	71-43-2	2.3E-08	3.5E-08	2.3E-08	3.6E-08
Trichloroethane, 1,1,2-	79-00-5	1.3E-08	2.1E-08	1.4E-08	2.1E-08
Trichloroethylene	79-01-6	2.9E-09	4.6E-09	3.0E-09	4.6E-09
Methylene chloride	75-09-2	1.7E-09	2.6E-09	1.7E-09	2.7E-09

**Table 6-5a. Inhalation Hazard Quotient for Central Tendency Landfill Area
(Small Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.00005	0.00005	0.00006	0.00006
Pyridine	110-86-1	0.00004	0.00004	0.00005	0.00005
Dichlorodifluoromethane	75-71-8	0.00003	0.00003	0.00003	0.00003
Methyl isobutyl ketone	108-10-1	0.00002	0.00002	0.00002	0.00002
Tetrachloroethylene	127-18-4	0.00002	0.00002	0.00002	0.00002
Nitrobenzene	98-95-3	0.00001	0.00001	0.00002	0.00002
Carbon disulfide	75-15-0	0.00001	0.00001	0.00001	0.00001
Trichlorofluoromethane	75-69-4	0.00001	0.00001	0.00001	0.00001
Toluene	108-88-3	0.000007	0.000007	0.000007	0.000007
Trichloroethane, 1,1,1-	71-55-6	0.000006	0.000006	0.000006	0.000006
Methyl ethyl ketone	78-93-3	0.000004	0.000004	0.000004	0.000004
Xylenes (total)	1330-20-7	0.000002	0.000002	0.000002	0.000002
Ethylbenzene	100-41-4	0.000001	0.000001	0.000001	0.000001
Ethoxyethanol, 2-	110-80-5	0.000001	0.000001	0.000001	0.000001
Methanol	67-56-1	0.0000004	0.0000004	0.0000004	0.0000004
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000003	0.0000003	0.0000003	0.0000003
Dichlorobenzene, 1,2-	95-50-1	0.0000002	0.0000002	0.0000003	0.0000003
Acetone	67-64-1	0.0000002	0.0000002	0.0000002	0.0000002
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available

**Table 6-5b. Inhalation Risk for Central Tendency Landfill Area
(Small Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	9.0E-07	1.4E-06	9.2E-07	1.4E-06
Carbon tetrachloride	56-23-5	9.2E-09	1.4E-08	9.4E-09	1.5E-08
Benzene	71-43-2	5.0E-09	7.7E-09	5.0E-09	7.8E-09
Trichloroethane, 1,1,2-	79-00-5	2.9E-09	4.6E-09	3.0E-09	4.7E-09
Trichloroethylene	79-01-6	6.4E-10	9.9E-10	6.5E-10	1.0E-09
Methylene chloride	75-09-2	3.7E-10	5.7E-10	3.7E-10	5.8E-10

**Table 6-6a. Inhalation Hazard Quotient for Central Tendency Landfill Area
(Small Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.00006	0.00006	0.00006	0.00006
Pyridine	110-86-1	0.00005	0.00005	0.00005	0.00005
Dichlorodifluoromethane	75-71-8	0.00003	0.00003	0.00004	0.00004
Methyl isobutyl ketone	108-10-1	0.00003	0.00003	0.00003	0.00003
Tetrachloroethylene	127-18-4	0.00002	0.00002	0.00002	0.00002
Nitrobenzene	98-95-3	0.00002	0.00002	0.00002	0.00002
Carbon disulfide	75-15-0	0.00001	0.00001	0.00001	0.00001
Trichlorofluoromethane	75-69-4	0.00001	0.00001	0.00001	0.00001
Toluene	108-88-3	0.000008	0.000008	0.000008	0.000008
Trichloroethane, 1,1,1-	71-55-6	0.000007	0.000007	0.000007	0.000007
Methyl ethyl ketone	78-93-3	0.000005	0.000005	0.000005	0.000005
Xylenes (total)	1330-20-7	0.000002	0.000002	0.000002	0.000002
Ethylbenzene	100-41-4	0.000002	0.000002	0.000002	0.000002
Ethoxyethanol, 2-	110-80-5	0.000001	0.000001	0.000001	0.000001
Methanol	67-56-1	0.0000003	0.0000003	0.0000003	0.0000003
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000003	0.0000003	0.0000003	0.0000003
Dichlorobenzene, 1,2-	95-50-1	0.0000003	0.0000003	0.0000004	0.0000004
Acetone	67-64-1	0.0000003	0.0000003	0.0000003	0.0000003
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available.

**Table 6-6b. Inhalation Risk for Central Tendency Landfill Area
(Small Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	1.1E-06	1.6E-06	1.1E-06	1.7E-06
Carbon tetrachloride	56-23-5	1.1E-08	1.7E-08	1.1E-08	1.7E-08
Benzene	71-43-2	5.7E-09	8.9E-09	5.8E-09	9.1E-09
Trichloroethane, 1,1,2-	79-00-5	3.4E-09	5.3E-09	3.5E-09	5.4E-09
Trichloroethylene	79-01-6	7.4E-10	1.1E-09	7.5E-10	1.2E-09
Methylene chloride	75-09-2	4.3E-10	6.6E-10	4.3E-10	6.7E-10

**Table 6-7a. Inhalation Hazard Quotient for Small Landfill Area
(Large Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.0003	0.0003	0.0004	0.0004
Pyridine	110-86-1	0.0003	0.0003	0.0003	0.0003
Dichlorodifluoromethane	75-71-8	0.0002	0.0002	0.0002	0.0002
Methyl isobutyl ketone	108-10-1	0.0001	0.0001	0.0002	0.0002
Tetrachloroethylene	127-18-4	0.0001	0.0001	0.0001	0.0001
Nitrobenzene	98-95-3	0.00009	0.00009	0.00013	0.00013
Carbon disulfide	75-15-0	0.00007	0.00007	0.00007	0.00007
Trichlorofluoromethane	75-69-4	0.00007	0.00007	0.00007	0.00007
Toluene	108-88-3	0.00005	0.00005	0.00005	0.00005
Trichloroethane, 1,1,1-	71-55-6	0.00004	0.00004	0.00004	0.00004
Methyl ethyl ketone	78-93-3	0.00003	0.00003	0.00003	0.00003
Xylenes (total)	1330-20-7	0.00001	0.00001	0.00001	0.00001
Ethylbenzene	100-41-4	0.000008	0.000008	0.000009	0.000009
Ethoxyethanol, 2-	110-80-5	0.000008	0.000008	0.000008	0.000008
Methanol	67-56-1	0.000002	0.000002	0.000002	0.000002
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000002	0.000002	0.000002	0.000002
Dichlorobenzene, 1,2-	95-50-1	0.000002	0.000002	0.000002	0.000002
Acetone	67-64-1	0.000002	0.000002	0.000002	0.000002
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available.

**Table 6-7b. Inhalation Risk for Small Landfill Area
(Large Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	5.8E-06	9.0E-06	5.9E-06	9.2E-06
Carbon tetrachloride	56-23-5	5.9E-08	9.2E-08	6.0E-08	9.4E-08
Benzene	71-43-2	3.2E-08	5.0E-08	3.2E-08	5.1E-08
Trichloroethane, 1,1,2-	79-00-5	1.9E-08	2.9E-08	1.9E-08	3.0E-08
Trichloroethylene	79-01-6	4.1E-09	6.4E-09	4.2E-09	6.5E-09
Methylene chloride	75-09-2	2.4E-09	3.7E-09	2.4E-09	3.8E-09

**Table 6-8a. Inhalation Hazard Quotient for Small Landfill Area
(Large Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.0004	0.0004	0.0004	0.0004
Pyridine	110-86-1	0.0003	0.0003	0.0004	0.0004
Dichlorodifluoromethane	75-71-8	0.0002	0.0002	0.0002	0.0002
Methyl isobutyl ketone	108-10-1	0.0002	0.0002	0.0002	0.0002
Tetrachloroethylene	127-18-4	0.0001	0.0001	0.0001	0.0001
Nitrobenzene	98-95-3	0.0001	0.0001	0.0002	0.0002
Carbon disulfide	75-15-0	0.00008	0.00008	0.00009	0.00009
Trichlorofluoromethane	75-69-4	0.00008	0.00008	0.00009	0.00009
Toluene	108-88-3	0.00006	0.00006	0.00006	0.00006
Trichloroethane, 1,1,1-	71-55-6	0.00005	0.00005	0.00005	0.00005
Methyl ethyl ketone	78-93-3	0.00003	0.00003	0.00003	0.00003
Xylenes (total)	1330-20-7	0.00002	0.00002	0.00002	0.00002
Ethylbenzene	100-41-4	0.00001	0.00001	0.00001	0.00001
Ethoxyethanol, 2-	110-80-5	0.000004	0.000004	0.000005	0.000005
Methanol	67-56-1	0.000002	0.000002	0.000002	0.000002
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000002	0.000002	0.000002	0.000002
Dichlorobenzene, 1,2-	95-50-1	0.000002	0.000002	0.000003	0.000003
Acetone	67-64-1	0.000002	0.000002	0.000002	0.000002
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available.

**Table 6-8b. Inhalation Risk for Small Landfill Area
(Large Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	7.2E-06	1.1E-05	7.4E-06	1.1E-05
Carbon tetrachloride	56-23-5	7.3E-08	1.1E-07	7.4E-08	1.2E-07
Benzene	71-43-2	3.9E-08	6.1E-08	4.0E-08	6.2E-08
Trichloroethane, 1,1,2-	79-00-5	2.3E-08	3.6E-08	2.4E-08	3.7E-08
Trichloroethylene	79-01-6	5.1E-09	7.9E-09	5.2E-09	8.0E-09
Methylene chloride	75-09-2	2.9E-09	4.6E-09	3.0E-09	4.6E-09

**Table 6-9a. Inhalation Hazard Quotient for Small Landfill Area
(Small Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.00009	0.00009	0.00009	0.00009
Pyridine	110-86-1	0.00007	0.00007	0.00007	0.00007
Dichlorodifluoromethane	75-71-8	0.00005	0.00005	0.00005	0.00005
Methyl isobutyl ketone	108-10-1	0.00004	0.00004	0.00004	0.00004
Tetrachloroethylene	127-18-4	0.00003	0.00003	0.00003	0.00003
Nitrobenzene	98-95-3	0.00002	0.00002	0.00003	0.00003
Carbon disulfide	75-15-0	0.00002	0.00002	0.00002	0.00002
Trichlorofluoromethane	75-69-4	0.00002	0.00002	0.00002	0.00002
Toluene	108-88-3	0.00001	0.00001	0.00001	0.00001
Trichloroethane, 1,1,1-	71-55-6	0.00001	0.00001	0.00001	0.00001
Methyl ethyl ketone	78-93-3	0.000007	0.000007	0.000007	0.000007
Xylenes (total)	1330-20-7	0.000003	0.000003	0.000003	0.000003
Ethylbenzene	100-41-4	0.000002	0.000002	0.000002	0.000002
Ethoxyethanol, 2-	110-80-5	0.000002	0.000002	0.000002	0.000002
Methanol	67-56-1	0.0000006	0.0000006	0.0000006	0.0000006
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000004	0.0000004	0.0000004	0.0000004
Dichlorobenzene, 1,2-	95-50-1	0.0000004	0.0000004	0.0000005	0.0000005
Acetone	67-64-1	0.0000004	0.0000004	0.0000004	0.0000004
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available.

**Table 6-9b. Inhalation Risk for Small Landfill Area
(Small Quantity Generator-Houston)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2- A16	79-46-9	1.5E-06	2.3E-06	1.5E-06	2.3E-06
Carbon tetrachloride	56-23-5	1.5E-08	2.3E-08	1.5E-08	2.4E-08
Benzene	71-43-2	8.0E-09	1.2E-08	8.2E-09	1.3E-08
Trichloroethane, 1,1,2-	79-00-5	4.7E-09	7.4E-09	4.9E-09	7.6E-09
Trichloroethylene	79-01-6	1.0E-09	1.6E-09	1.1E-09	1.6E-09
Methylene chloride	75-09-2	5.9E-10	9.3E-10	6.1E-10	9.4E-10

**Table 6-10a. Inhalation Hazard Quotient for Small Landfill Area
(Small Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation HQ Adult	Inhalation HQ Child	Inhalation HQ Adult	Inhalation HQ Child
Chlorobenzene	108-90-7	0.0001	0.0001	0.0001	0.0001
Pyridine	110-86-1	0.00008	0.00008	0.00009	0.00009
Dichlorodifluoromethane	75-71-8	0.00006	0.00006	0.00006	0.00006
Methyl isobutyl ketone	108-10-1	0.00005	0.00005	0.00005	0.00005
Tetrachloroethylene	127-18-4	0.00003	0.00003	0.00003	0.00003
Nitrobenzene	98-95-3	0.00003	0.00003	0.00004	0.00004
Carbon disulfide	75-15-0	0.00002	0.00002	0.00002	0.00002
Trichlorofluoromethane	75-69-4	0.00002	0.00002	0.00002	0.00002
Toluene	108-88-3	0.00001	0.00001	0.00001	0.00001
Trichloroethane, 1,1,1-	71-55-6	0.00001	0.00001	0.00001	0.00001
Methyl ethyl ketone	78-93-3	0.000008	0.000008	0.000008	0.000008
Xylenes (total)	1330-20-7	0.000004	0.000004	0.000004	0.000004
Ethylbenzene	100-41-4	0.000003	0.000003	0.000003	0.000003
Ethoxyethanol, 2-	110-80-5	0.000001	0.000001	0.000001	0.000001
Methanol	67-56-1	0.0000005	0.0000005	0.0000006	0.0000006
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000005	0.0000005	0.0000005	0.0000005
Dichlorobenzene, 1,2-	95-50-1	0.0000005	0.0000005	0.0000006	0.0000006
Acetone	67-64-1	0.0000004	0.0000004	0.0000005	0.0000005
Ethyl ether	60-29-7	NA	NA	NA	NA
Butanol	71-36-3	NA	NA	NA	NA
Isobutyl alcohol	78-83-1	NA	NA	NA	NA
o-Xylene	95-47-6	NA	NA	NA	NA
Cresol, o-	95-48-7	NA	NA	NA	NA
Cresol, p-	106-44-5	NA	NA	NA	NA
m-Xylene	108-38-3	NA	NA	NA	NA
Cresol, m-	108-39-4	NA	NA	NA	NA
Cyclohexanone	108-94-1	NA	NA	NA	NA
Ethyl acetate	141-78-6	NA	NA	NA	NA

NA = Not available.

**Table 6-10b. Inhalation Risk for Small Landfill Area
(Small Quantity Generator-Lincoln)**

Constituent	CAS	6hr		12hr	
		Inhalation Risk Adult	Inhalation Risk Child	Inhalation Risk Adult	Inhalation Risk Child
Nitropropane, 2-	79-46-9	1.8E-06	2.8E-06	1.9E-06	2.9E-06
Carbon tetrachloride	56-23-5	1.8E-08	2.9E-08	1.9E-08	2.9E-08
Benzene	71-43-2	9.9E-09	1.5E-08	1.0E-08	1.6E-08
Trichloroethane, 1,1,2-	79-00-5	5.8E-09	9.1E-09	6.0E-09	9.3E-09
Trichloroethylene	79-01-6	1.3E-09	2.0E-09	1.3E-09	2.0E-09
Methylene chloride	75-09-2	7.4E-10	1.1E-09	7.5E-10	1.2E-09

**Table 6-11a. Drinking Water Ingestion Hazard Quotient for
Central Tendency Landfill Area (Large Quantity Generator-Houston)**

Constituent	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		12hr		12hr		12hr	
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine	110-86-1	20	30	138	206	2	4
Nitrobenzene	98-95-3	1	2	7	14	0.1	0.2
Cresol, p-	106-44-5	0.6	1	4	7	0.07	0.1
Acetone	67-64-1	0.1	0.2	0.7	1	0.01	0.02
Butanol	71-36-3	0.1	0.2	0.7	1	0.01	0.02
Methyl isobutyl ketone	108-10-1	0.1	0.2	0.7	1	0.01	0.02
Ethyl ether	60-29-7	0.05	0.08	0.3	0.6	0.006	0.01
Isobutyl alcohol	78-83-1	0.05	0.09	0.3	0.6	0.006	0.01
Cresol, m-	108-39-4	0.05	0.08	0.3	0.6	0.006	0.01
Ethoxyethanol, 2-	110-80-5	0.05	0.08	0.3	0.6	0.006	0.01
Methanol	67-56-1	0.04	0.06	0.3	0.4	0.005	0.007
Methyl ethyl ketone	78-93-3	0.03	0.05	0.2	0.3	0.004	0.006
Cresol, o-	95-48-7	0.03	0.04	0.2	0.3	0.004	0.005
Carbon disulfide	75-15-0	0.02	0.03	0.1	0.2	0.002	0.004
Ethyl acetate	141-78-6	0.02	0.03	0.1	0.2	0.002	0.004
Tetrachloroethylene	127-18-4	0.005	0.008	0.03	0.06	0.0006	0.001
Cyclohexanone	108-94-1	0.004	0.006	0.03	0.04	0.0005	0.0007
Chlorobenzene	108-90-7	0.003	0.005	0.02	0.03	0.0004	0.0006
Ethylbenzene	100-41-4	0.001	0.002	0.01	0.01	0.0001	0.0002
Toluene	108-88-3	0.001	0.002	0.007	0.01	0.0001	0.0002
Dichlorodifluoromethane	75-71-8	0.0005	0.0008	0.003	0.006	0.00006	0.0001
Trichloroethane, 1,1,1-	71-55-6	0.0004	0.0006	0.003	0.004	0.00005	0.00007
Trichlorofluoromethane	75-69-4	0.0002	0.0003	0.001	0.002	0.00002	0.00004
Dichlorobenzene, 1,2-	95-50-1	0.0002	0.0003	0.001	0.002	0.00002	0.00004
o-Xylene	95-47-6	0.0001	0.0002	0.001	0.001	0.00001	0.00002
m-Xylene	108-38-3	0.00009	0.0002	0.0006	0.001	0.00001	0.00002
Xylenes (total)	1330-20-7	0.00004	0.00007	0.0003	0.0005	0.000005	0.000008
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000004	0.000007	0.00003	0.00005	0.0000005	0.0000008

**Table 6-11b. Drinking Water Ingestion Risk for
Central Tendency Landfill Area (Large Quantity Generator-Houston)**

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	3.9E-06	4.8E-06	8.3E-05	1.0E-04	4.7E-07	5.8E-07
Benzene	71-43-2	3.4E-06	4.2E-06	7.2E-05	8.8E-05	4.1E-07	5.0E-07
Trichloroethane, 1,1,2-	79-00-5	1.9E-06	2.3E-06	3.9E-05	4.8E-05	2.2E-07	2.7E-07
Carbon tetrachloride	56-23-5	6.9E-07	8.4E-07	1.5E-05	1.8E-05	8.3E-08	1.0E-07
Trichloroethylene	79-01-6	7.3E-08	8.9E-08	1.5E-06	1.9E-06	8.7E-09	1.1E-08
Nitropropane, 2-	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

**Table 6-12a. Drinking Water Ingestion Hazard Quotient for
Central Tendency Landfill Area (Large Quantity Generator-Lincoln)**

Pyridine	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		12hr					
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine**	110-86-1	4	7	28	48	0.8	1
Nitrobenzene	98-95-3	0.3	0.4	2	3	0.06	0.08
Cresol, p-	106-44-5	0.1	0.2	0.7	1	0.02	0.04
Acetone	67-64-1	0.04	0.06	0.3	0.4	0.01	0.01
Butanol	71-36-3	0.04	0.06	0.3	0.4	0.01	0.01
Methyl isobutyl ketone	108-10-1	0.03	0.05	0.2	0.3	0.006	0.010
Ethyl ether	60-29-7	0.01	0.02	0.07	0.1	0.002	0.004
Ethoxyethanol, 2-	78-83-1	0.01	0.02	0.07	0.1	0.002	0.004
Cresol, m-	108-39-4	0.01	0.02	0.07	0.1	0.002	0.004
Ethoxyethanol, 2- **	110-80-5	0.01	0.02	0.07	0.1	0.002	0.004
Methanol	67-56-1	0.009	0.01	0.06	0.07	0.002	0.002
Methyl ethyl ketone	78-93-3	0.007	0.01	0.05	0.07	0.001	0.002
Cresol, o-	95-48-7	0.006	0.01	0.04	0.07	0.001	0.002
Carbon disulfide	75-15-0	0.004	0.007	0.03	0.05	0.0008	0.001
Ethyl acetate	141-78-6	0.004	0.007	0.03	0.05	0.0008	0.001
Tetrachloroethylene	127-18-4	0.001	0.002	0.01	0.01	0.0002	0.0004
Cyclohexanone	108-94-1	0.0009	0.002	0.006	0.014	0.0002	0.0004
Chlorobenzene	108-90-7	0.0007	0.001	0.005	0.007	0.0001	0.0002
Ethylbenzene	100-41-4	0.0004	0.0006	0.003	0.004	0.00008	0.0001
Toluene	108-88-3	0.0003	0.0005	0.002	0.003	0.00006	0.0001
Trichloroethane, 1,1,1-	71-55-6	0.0001	0.0002	0.001	0.001	0.00002	0.00004
Dichlorodifluoromethane	75-71-8	0.0001	0.0002	0.0007	0.001	0.00002	0.00004
Trichlorofluoromethane	75-69-4	0.00005	0.00008	0.0003	0.0006	0.00001	0.00002
Dichlorobenzene, 1,2-	95-50-1	0.00004	0.00007	0.0003	0.0005	0.00001	0.00001
o-Xylene	95-47-6	0.00003	0.00004	0.0002	0.0003	0.000006	0.000008
m-Xylene	108-38-3	0.00002	0.00004	0.0001	0.0003	0.000004	0.000008
Xylenes (total)	1330-20-7	0.00001	0.00002	0.00007	0.0001	0.000002	0.000004
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000001	0.000002	0.000007	0.0000	0.0000002	0.0000004

**Table 6-12b. Drinking Water Ingestion Risk for
Central Tendency Landfill Area (Large Quantity Generator-Lincoln)**

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	1.0E-06	1.2E-06	6.9E-06	8.4E-06	1.9E-07	2.3E-07
Benzene	71-43-2	8.7E-07	1.1E-06	6.0E-06	7.3E-06	1.7E-07	2.0E-07
Trichloroethane, 1,1,2-	79-00-5	4.7E-07	5.8E-07	3.2E-06	4.0E-06	9.0E-08	1.1E-07
Carbon tetrachloride	56-23-5	1.7E-07	2.1E-07	1.2E-06	1.5E-06	3.3E-08	4.1E-08
Trichloroethylene	79-01-6	1.8E-08	2.2E-08	1.3E-07	1.5E-07	3.5E-09	4.3E-09
Nitropropane, 2- *	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

Table 6-13a. Drinking Water Ingestion Hazard Quotient for Central Tendency Landfill Area (Small Quantity Generator-Houston)

Constituent	CAS	National Average X-Well 12hr		25 Ft X-Well		National Average X-Well and Liner	
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine	110-86-1	4	7	28	48	0.5	0.8
Nitrobenzene	98-95-3	0.3	0.4	2	3	0.04	0.05
Cresol, p-	106-44-5	0.1	0.2	0.7	1	0.01	0.02
Acetone	67-64-1	0.04	0.06	0.3	0.4	0.005	0.007
Butanol	71-36-3	0.04	0.06	0.3	0.4	0.005	0.007
Methyl isobutyl ketone	108-10-1	0.03	0.05	0.2	0.3	0.004	0.006
Ethyl ether	60-29-7	0.01	0.02	0.1	0.1	0.001	0.002
Isobutyl alcohol	78-83-1	0.01	0.02	0.07	0.1	0.001	0.002
Cresol, m-	108-39-4	0.01	0.02	0.07	0.1	0.001	0.002
Ethoxyethanol, 2-	110-80-5	0.01	0.02	0.07	0.1	0.001	0.002
Methanol	67-56-1	0.009	0.01	0.06	0.07	0.001	0.001
Methyl ethyl ketone	78-93-3	0.007	0.01	0.05	0.07	0.0008	0.001
Cresol, o-	95-48-7	0.006	0.01	0.04	0.07	0.0007	0.001
Carbon disulfide	75-15-0	0.004	0.007	0.03	0.05	0.0005	0.0008
Ethyl acetate	141-78-6	0.004	0.007	0.03	0.05	0.0005	0.0008
Tetrachloroethylene	127-18-4	0.001	0.002	0.01	0.01	0.0001	0.0002
Cyclohexanone	108-94-1	0.0009	0.002	0.006	0.014	0.0001	0.0002
Chlorobenzene	108-90-7	0.0007	0.001	0.005	0.007	0.00008	0.0001
Ethylbenzene	100-41-4	0.0004	0.0006	0.003	0.004	0.00005	0.00007
Toluene	108-88-3	0.0003	0.0005	0.002	0.003	0.00004	0.00006
Trichloroethane, 1,1,1-	71-55-6	0.0001	0.0002	0.001	0.001	0.00001	0.00002
Dichlorodifluoromethane	75-71-8	0.0001	0.0002	0.0007	0.001	0.00001	0.00002
Trichlorofluoromethane	75-69-4	0.00004	0.00007	0.0003	0.0005	0.000005	0.000008
Dichlorobenzene, 1,2-	95-50-1	0.00004	0.00007	0.0003	0.0005	0.000005	0.000008
o-Xylene	95-47-6	0.00003	0.00004	0.0002	0.0003	0.000004	0.000005
m-Xylene	108-38-3	0.00002	0.00004	0.0001	0.0003	0.000002	0.000005
Xylenes (total)	1330-20-7	0.00001	0.00002	0.00007	0.0001	0.000001	0.000002
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000001	0.000002	0.000007	0.00001	0.0000001	0.0000002

Table 6-13b. Drinking Water Ingestion Risk for Central Tendency Landfill Area (Small Quantity Generator-Houston)

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	9.9E-07	1.2E-06	6.8E-06	8.3E-06	1.2E-07	1.5E-07
Benzene	71-43-2	8.6E-07	1.1E-06	5.9E-06	7.3E-06	1.0E-07	1.3E-07
Trichloroethane, 1,1,2-	79-00-5	4.7E-07	5.8E-07	3.2E-06	4.0E-06	5.7E-08	6.9E-08
Carbon tetrachloride	56-23-5	1.7E-07	2.1E-07	1.2E-06	1.5E-06	2.1E-08	2.5E-08
Trichloroethylene	79-01-6	1.8E-08	2.2E-08	1.3E-07	1.5E-07	2.2E-09	2.7E-09
Nitropropane, 2- *	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

**Table 6-14a. Drinking Water Ingestion Hazard Quotient for
Central Tendency Landfill Area (Small Quantity Generator-Lincoln)**

Constituent	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine	110-86-1	4	7	27.5	48.125	0.76	1.33
Nitrobenzene	98-95-3	0.3	0.4	2.0625	2.75	0.057	0.076
Cresol, p-	106-44-5	0.1	0.2	0.6875	1.375	0.019	0.038
Acetone	67-64-1	0.04	0.06	0.275	0.4125	0.0076	0.0114
Butanol	71-36-3	0.04	0.06	0.275	0.4125	0.0076	0.0114
Methyl isobutyl ketone	108-10-1	0.03	0.05	0.20625	0.34375	0.0057	0.0095
Ethyl ether	60-29-7	0.01	0.02	0.06875	0.1375	0.0019	0.0038
Isobutyl alcohol	78-83-1	0.01	0.02	0.06875	0.1375	0.0019	0.0038
Cresol, m-	108-39-4	0.01	0.02	0.06875	0.1375	0.0019	0.0038
Ethoxyethanol, 2-	110-80-5	0.01	0.02	0.06875	0.1375	0.0019	0.0038
Methanol	67-56-1	0.009	0.01	0.061875	0.06875	0.00171	0.0019
Methyl ethyl ketone	78-93-3	0.007	0.01	0.048125	0.06875	0.00133	0.0019
Cresol, o-	95-48-7	0.006	0.01	0.04125	0.06875	0.00114	0.0019
Carbon disulfide	75-15-0	0.004	0.007	0.0275	0.048125	0.00076	0.00133
Ethyl acetate	141-78-6	0.004	0.007	0.0275	0.048125	0.00076	0.00133
Tetrachloroethylene	127-18-4	0.001	0.002	0.006875	0.01375	0.00019	0.00038
Cyclohexanone	108-94-1	0.0009	0.002	0.006188	0.01375	0.000171	0.00038
Chlorobenzene	108-90-7	0.0007	0.001	0.004813	0.006875	0.000133	0.00019
Ethylbenzene	100-41-4	0.0004	0.0006	0.00275	0.004125	0.000076	0.000114
Toluene	108-88-3	0.0003	0.0005	0.002063	0.003438	0.000057	0.000095
Trichloroethane, 1,1,1-	71-55-6	0.0001	0.0002	0.000688	0.001375	0.000019	0.000038
Dichlorodifluoromethane	75-71-8	0.0001	0.0002	0.000688	0.001375	0.000019	0.000038
Trichlorofluoromethane	75-69-4	0.00005	0.00008	0.000344	0.00055	9.5E-06	1.52E-05
Dichlorobenzene, 1,2-	95-50-1	0.00004	0.00007	0.000275	0.000481	7.6E-06	1.33E-05
o-Xylene	95-47-6	0.00003	0.00004	0.000206	0.000275	5.7E-06	7.6E-06
m-Xylene	108-38-3	0.00002	0.00004	0.000138	0.000275	3.8E-06	7.6E-06
Xylenes (total)	1330-20-7	0.00001	0.00002	6.88E-05	0.000138	1.9E-06	3.8E-06
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000001	0.000002	6.88E-06	1.38E-05	1.9E-07	3.8E-07

**Table 6-14b. Drinking Water Ingestion Risk for
Central Tendency Landfill Area (Small Quantity Generator-Lincoln)**

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	1.0E-06	1.2E-06	6.9E-06	8.4E-06	1.9E-07	2.3E-07
Benzene	71-43-2	8.7E-07	1.1E-06	6.0E-06	7.3E-06	1.7E-07	2.0E-07
Trichloroethane, 1,1,2-	79-00-5	4.7E-07	5.8E-07	3.2E-06	4.0E-06	9.0E-08	1.1E-07
Carbon tetrachloride	56-23-5	1.7E-07	2.1E-07	1.2E-06	1.5E-06	3.3E-08	4.1E-08
Trichloroethylene	79-01-6	1.8E-08	2.2E-08	1.3E-07	1.5E-07	3.5E-09	4.3E-09
Nitropropane, 2-	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

Table 6-15a. Drinking Water Ingestion Hazard Quotient for Small Landfill Area (Large Quantity Generator-Houston)

Constituent	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner							
		12hr		12hr		12hr							
		DW Adult	HQ Child	DW Adult	HQ Child	DW Adult	HQ Child						
Pyridine	110-86-1		50		90		482	868		6		11	
Nitrobenzene	98-95-3		3		5		29		48		0.4		0.6
Cresol, p-	106-44-5		2		3		19		29		0.24		0.36
Butanol	71-36-3		0.5		0.8		5		8		0.06		0.10
Acetone	67-64-1		0.4		0.7		4		7		0.05		0.08
Methyl isobutyl ketone	108-10-1		0.3		0.6		3		6		0.04		0.07
Ethyl ether	60-29-7		0.2		0.3		2		3		0.02		0.04
Isobutyl alcohol	78-83-1		0.2		0.3		2		3		0.02		0.04
Ethoxyethanol, 2-	110-80-5		0.2		0.3		2		3		0.02		0.04
Methanol	67-56-1		0.1		0.2		1		2		0.01		0.02
Cresol, m-	108-39-4		0.1		0.2		1		2		0.01		0.02
Methyl ethyl ketone	78-93-3		0.08		0.1		0.8		1.0		0.010		0.01
Cresol, o-	95-48-7		0.08		0.1		0.8		1.0		0.010		0.01
Carbon disulfide	75-15-0		0.05		0.08		0.5		0.8		0.006		0.010
Ethyl acetate	141-78-6		0.05		0.08		0.5		0.8		0.006		0.010
Cyclohexanone	108-94-1		0.01		0.02		0.1		0.2		0.001		0.002
Tetrachloroethylene	127-18-4		0.01		0.02		0.1		0.2		0.001		0.002
Chlorobenzene	108-90-7		0.009		0.02		0.1		0.2		0.001		0.002
Ethylbenzene	100-41-4		0.004		0.007		0.04		0.07		0.0005		0.0008
Toluene	108-88-3		0.003		0.006		0.03		0.06		0.0004		0.0007
Dichlorodifluoromethane	75-71-8		0.002		0.003		0.02		0.03		0.0002		0.0004
Trichloroethane, 1,1,1-	71-55-6		0.001		0.002		0.01		0.02		0.0001		0.0002
Trichlorofluoromethane	75-69-4		0.0005		0.0009		0.005		0.009		0.00006		0.0001
Dichlorobenzene, 1,2-	95-50-1		0.0005		0.0008		0.005		0.008		0.00006		0.000096
o-Xylene	95-47-6		0.0003		0.0005		0.003		0.005		0.00004		0.00006
m-Xylene	108-38-3		0.0003		0.0005		0.003		0.005		0.000036		0.00006
Xylenes (total)	1330-20-7		0.0001		0.0002		0.001		0.002		0.00001		0.00002
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1		0.00001		0.00002		0.0001		0.0002		0.000001		0.000002

Table 6-15b. Drinking Water Ingestion Risk for Small Landfill Area (Large Quantity Generator-Houston)

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	1.2E-05	1.5E-05	1.2E-04	1.4E-04	1.4E-06	1.8E-06
Benzene	71-43-2	1.0E-05	1.3E-05	1.0E-04	1.2E-04	1.3E-06	1.5E-06
Trichloroethane, 1,1,2-	79-00-5	5.7E-06	7.0E-06	5.5E-05	6.7E-05	6.9E-07	8.4E-07
Carbon tetrachloride	56-23-5	2.1E-06	2.6E-06	2.0E-05	2.5E-05	2.5E-07	3.1E-07
Trichloroethylene	79-01-6	2.2E-07	2.7E-07	2.1E-06	2.6E-06	2.7E-08	3.3E-08
Nitropropane, 2-	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

**Table 6-16a. Drinking Water Ingestion Hazard Quotient for
Small Landfill Area (Large Quantity Generator-Lincoln)**

Pyridine	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		12hr					
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine	110-86-1	2	3	19	29	0.4	0.6
Nitrobenzene	98-95-3	0.1	0.2	1	2	0.02	0.04
Cresol, p-	106-44-5	0.06	0.1	0.6	1.0	0.01	0.02
Butanol	71-36-3	0.02	0.03	0.2	0.3	0.004	0.006
Acetone	67-64-1	0.01	0.02	0.1	0.2	0.002	0.004
Methyl isobutyl ketone	108-10-1	0.01	0.02	0.1	0.2	0.002	0.004
Isobutyl alcohol	78-83-1	0.006	0.009	0.06	0.09	0.001	0.002
Ethyl ether	60-29-7	0.005	0.009	0.05	0.09	0.001	0.002
Ethoxyethanol, 2-	108-39-4	0.005	0.008	0.05	0.08	0.001	0.002
Ethoxyethanol, 2- **	110-80-5	0.005	0.009	0.05	0.09	0.001	0.002
Methanol	67-56-1	0.004	0.006	0.04	0.06	0.001	0.001
Methyl ethyl ketone	78-93-3	0.003	0.005	0.03	0.05	0.0006	0.001
Cresol, o-	95-48-7	0.003	0.004	0.03	0.04	0.0006	0.0008
Carbon disulfide	75-15-0	0.002	0.003	0.02	0.03	0.0004	0.0006
Ethyl acetate	141-78-6	0.002	0.003	0.02	0.03	0.0004	0.0006
Tetrachloroethylene	127-18-4	0.0005	0.0008	0.005	0.008	0.0001	0.0002
Cyclohexanone	108-94-1	0.0004	0.0006	0.004	0.006	0.0001	0.0001
Chlorobenzene	108-90-7	0.0003	0.0005	0.003	0.005	0.0001	0.0001
Ethylbenzene	100-41-4	0.0001	0.0002	0.001	0.002	0.00002	0.00004
Toluene	108-88-3	0.0001	0.0002	0.001	0.002	0.00002	0.00004
Dichlorodifluoromethane	75-71-8	0.00005	0.00009	0.0005	0.0009	0.00001	0.00002
Trichloroethane, 1,1,1-	71-55-6	0.00004	0.00007	0.0004	0.0007	0.00001	0.00001
Trichlorofluoromethane	75-69-4	0.00002	0.00003	0.0002	0.0003	0.000004	0.000006
Dichlorobenzene, 1,2-	95-50-1	0.00002	0.00003	0.0002	0.0003	0.000004	0.000006
o-Xylene	95-47-6	0.00001	0.00002	0.0001	0.0002	0.000002	0.000004
m-Xylene	108-38-3	0.000009	0.00002	0.0001	0.0002	0.000002	0.000004
Xylenes (total)	1330-20-7	0.000004	0.000007	0.00004	0.00007	0.0000008	0.000001
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000004	0.0000007	0.000004	0.000007	0.00000008	0.0000001

**Table 6-16b. Drinking Water Ingestion Risk for
Small Landfill Area (Large Quantity Generator-Lincoln)**

Constituent	CAS	12hr		12hr		12hr	
		DW Risk	DW Risk	DW Risk	DW Risk	DW Risk	DW Risk
		Adult	Child	Adult	Child	Adult	Child
Methylene chloride	75-09-2	4.1E-07	5.0E-07	3.9E-06	4.8E-06	7.8E-08	9.5E-08
Benzene	71-43-2	3.5E-07	4.3E-07	3.4E-06	4.2E-06	6.7E-08	8.2E-08
Trichloroethane, 1,1,2-	79-00-5	1.9E-07	2.3E-07	1.9E-06	2.3E-06	3.7E-08	4.5E-08
Carbon tetrachloride	56-23-5	7.1E-08	8.7E-08	6.9E-07	8.4E-07	1.4E-08	1.7E-08
Nitropropane, 2-	79-01-6	7.5E-09	9.1E-09	7.2E-08	8.8E-08	1.4E-09	1.7E-09
Nitropropane, 2- *	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

Table 6-17a. Drinking Water Ingestion Hazard Quotient for Small Landfill Area (Small Quantity Generator-Houston)

Constituent	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		12hr					
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine**	110-86-1	10	20	96	193	1	2
Nitrobenzene	98-95-3	0.8	1	8	10	0.1	0.1
Cresol, p-	106-44-5	0.4	0.7	4	7	0.05	0.08
Acetone	67-64-1	0.1	0.2	1	2	0.01	0.02
Butanol	71-36-3	0.1	0.2	1	2	0.01	0.02
Methyl isobutyl ketone	108-10-1	0.08	0.1	0.8	1.0	0.01	0.01
Ethyl ether	60-29-7	0.04	0.06	0.4	0.6	0.005	0.007
Isobutyl alcohol	78-83-1	0.04	0.07	0.4	0.7	0.005	0.008
Cresol, m-	108-39-4	0.04	0.06	0.4	0.6	0.005	0.007
Ethoxyethanol, 2- **	110-80-5	0.04	0.06	0.4	0.6	0.005	0.007
Methanol	67-56-1	0.03	0.05	0.3	0.5	0.004	0.006
Methyl ethyl ketone	78-93-3	0.02	0.03	0.2	0.3	0.002	0.004
Cresol, o-	95-48-7	0.02	0.03	0.2	0.3	0.002	0.004
Carbon disulfide	75-15-0	0.01	0.02	0.1	0.2	0.001	0.002
Ethyl acetate	141-78-6	0.01	0.02	0.1	0.2	0.001	0.002
Tetrachloroethylene	127-18-4	0.004	0.006	0.04	0.06	0.0005	0.0007
Cyclohexanone	108-94-1	0.003	0.005	0.03	0.05	0.0004	0.0006
Chlorobenzene	108-90-7	0.002	0.004	0.02	0.04	0.0002	0.0005
Ethylbenzene	100-41-4	0.001	0.002	0.01	0.02	0.0001	0.0002
Toluene	108-88-3	0.0009	0.001	0.009	0.010	0.0001	0.0001
Dichlorodifluoromethane	75-71-8	0.0004	0.0006	0.004	0.006	0.00005	0.00007
Trichloroethane, 1,1,1-	71-55-6	0.0003	0.0005	0.003	0.005	0.00004	0.00006
Trichlorofluoromethane	75-69-4	0.0001	0.0002	0.001	0.002	0.00001	0.00002
Dichlorobenzene, 1,2-	95-50-1	0.0001	0.0002	0.001	0.002	0.00001	0.00002
o-Xylene	95-47-6	0.00008	0.0001	0.001	0.001	0.00001	0.00001
m-Xylene	108-38-3	0.00007	0.0001	0.0007	0.0010	0.000008	0.000012
Xylenes (total)	1330-20-7	0.00003	0.00005	0.0003	0.0005	0.000004	0.000006
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.000003	0.000005	0.00003	0.00005	0.0000004	0.0000006

Table 6-17b. Drinking Water Ingestion Risk for Small Landfill Area (Small Quantity Generator-Houston)

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	3.0E-06	3.7E-06	2.9E-05	3.6E-05	3.6E-07	4.4E-07
Benzene	71-43-2	2.6E-06	3.2E-06	2.5E-05	3.1E-05	3.2E-07	3.9E-07
Trichloroethane, 1,1,2-	79-00-5	1.4E-06	1.8E-06	1.4E-05	1.7E-05	1.7E-07	2.1E-07
Carbon tetrachloride	56-23-5	5.3E-07	6.5E-07	5.1E-06	6.3E-06	6.4E-08	7.8E-08
Trichloroethylene	79-01-6	5.6E-08	6.8E-08	5.4E-07	6.6E-07	6.7E-09	8.2E-09
Nitropropane, 2- *	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not Available.

**Table 6-18a. Drinking Water Ingestion Hazard Quotient for
Small Landfill Area (Small Quantity Generator-Lincoln)**

Pyridine	CAS	National Average X-Well		25 Ft X-Well		National Average X-Well and Liner	
		12hr					
		DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child	DW HQ Adult	DW HQ Child
Pyridine**	110-86-1	2.0	3.0	19	29	0.4	0.6
Nitrobenzene	98-95-3	0.1	0.2	1	2	0.02	0.04
Cresol, p-	106-44-5	0.1	0.1	1	1	0.01	0.02
Butanol	71-36-3	0.02	0.03	0.2	0.3	0.004	0.006
Acetone	67-64-1	0.01	0.02	0.1	0.2	0.002	0.004
Methyl isobutyl ketone	108-10-1	0.01	0.02	0.1	0.2	0.002	0.004
Isobutyl alcohol	78-83-1	0.01	0.01	0.1	0.1	0.001	0.002
Ethoxyethanol, 2-	60-29-7	0.005	0.009	0.05	0.09	0.001	0.002
Cresol, m-	108-39-4	0.005	0.008	0.05	0.08	0.001	0.002
Ethoxyethanol, 2- **	110-80-5	0.005	0.009	0.05	0.09	0.001	0.002
Methanol	67-56-1	0.004	0.006	0.04	0.06	0.0008	0.001
Methyl ethyl ketone	78-93-3	0.003	0.005	0.03	0.05	0.0006	0.0010
Cresol, o-	95-48-7	0.003	0.004	0.03	0.04	0.0006	0.0008
Carbon disulfide	75-15-0	0.002	0.003	0.02	0.03	0.0004	0.0006
Ethyl acetate	141-78-6	0.002	0.003	0.02	0.03	0.0004	0.0006
Tetrachloroethylene	127-18-4	0.001	0.001	0.005	0.008	0.0001	0.0002
Cyclohexanone	108-94-1	0.0004	0.0006	0.004	0.006	0.00008	0.0001
Chlorobenzene	108-90-7	0.0003	0.0005	0.003	0.005	0.00006	0.0001
Ethylbenzene	100-41-4	0.0001	0.0002	0.001	0.002	0.00002	0.00004
Toluene	108-88-3	0.0001	0.0002	0.001	0.002	0.00002	0.00004
Dichlorodifluoromethane	75-71-8	0.0001	0.0001	0.0005	0.0009	0.00001	0.00002
Trichloroethane, 1,1,1-	71-55-6	0.00004	0.00007	0.0004	0.0007	0.000008	0.000013
Trichlorofluoromethane	75-69-4	0.00002	0.00003	0.0002	0.0003	0.000004	0.000006
Dichlorobenzene, 1,2-	95-50-1	0.00002	0.00003	0.0002	0.0003	0.000004	0.000006
o-Xylene	95-47-6	0.00001	0.00002	0.0001	0.0002	0.000002	0.000004
m-Xylene	108-38-3	0.00001	0.00002	0.0001	0.0002	0.000002	0.000004
Xylenes (total)	1330-20-7	0.000004	0.000007	0.00004	0.00007	0.0000008	0.000001
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	0.0000004	0.0000007	0.000004	0.000007	0.00000008	0.0000001

**Table 6-18b. Drinking Water Ingestion Risk for
Small Landfill Area (Small Quantity Generator-Lincoln)**

Constituent	CAS	12hr		12hr		12hr	
		DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child	DW Risk Adult	DW Risk Child
Methylene chloride	75-09-2	4.1E-07	5.0E-07	3.9E-06	4.8E-06	7.8E-08	9.5E-08
Benzene	71-43-2	3.5E-07	4.3E-07	3.4E-06	4.2E-06	6.7E-08	8.2E-08
Trichloroethane, 1,1,2-	79-00-5	1.9E-07	2.3E-07	1.9E-06	2.3E-06	3.7E-08	4.5E-08
Carbon tetrachloride	56-23-5	7.1E-08	8.7E-08	6.9E-07	8.4E-07	1.4E-08	1.7E-08
Trichloroethylene	79-01-6	7.5E-09	9.1E-09	7.2E-08	8.8E-08	1.4E-09	1.7E-09
Nitropropane, 2-	79-46-9	NA	NA	NA	NA	NA	NA

NA = Not available.

Table 6-19. Risk Factors

Compound	CAS No.	Groundwater concentration (mg/L)	Inhalation hazard quotient for shower	Inhalation hazard quotient for bathroom	Inhalation hazard quotient for whole house	Summed inhalation hazard quotient or risk
Carbon tetrachloride	56-23-5	1	1.E-04	1.E-04	1.E-05	2.E-04
Ethyl ether	60-29-7	1	NA	NA	NA	NA
Methanol	67-56-1	1	0.01	0.003	0.00002	0.01
Acetone	67-64-1	1	0.04	0.008	0.00005	0.05
Butanol	71-36-3	1	NA	NA	NA	NA
Benzene	71-43-2	1	8.E-05	5.E-05	6.E-06	1.E-04
1,1,1-Trichloroethane	71-55-6	1	9	4	0.03	10
Methylene chloride	75-09-2	1	4.E-06	3.E-06	3.E-07	7.E-06
Carbon disulfide	75-15-0	1	10	6	0.04	20
Trichlorofluoromethane	75-69-4	1	40	6	0.04	16
Dichlorodifluoromethane	75-71-8	1	40	20	0.1	60
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	1	0.3	0.1	0.0009	0.4
Isobutyl alcohol	78-83-1	1	NA	NA	NA	NA
Methyl ethyl ketone	78-93-3	1	2	0.3	0.002	2
1,1,2-Trichloroethane	79-00-5	1	1.E-04	6.E-05	7.E-06	2.E-04
Trichloroethylene	79-01-6	1	0.00002	0.00001	0.000001	0.00003
2-Nitropropane	79-46-9	1	9.E-03	3.E-03	3.E-04	1.E-02
o-Xylene	95-47-6	1	NA	NA	NA	NA
o-Cresol	95-48-7	1	NA	NA	NA	NA
1,2-Dichlorobenzene	95-50-1	1	40	10	0.09	50
Nitrobenzene	98-95-3	1	400	70	0.5	500
Ethylbenzene	100-41-4	1	9	4	0.02	10
p-Cresol	106-44-5	1	NA	NA	NA	NA
Methyl isobutyl ketone	108-10-1	1	50	9	0.06	60
m-Xylene	108-38-3	1	NA	NA	NA	NA
m-Cresol	108-39-4	1	NA	NA	NA	NA
Toluene	108-88-3	1	20	9	0.06	30
Chlorobenzene	108-90-7	1	400	200	1	600
Cyclohexanone	108-94-1	1	NA	NA	NA	NA
2-Ethoxyethanol	110-80-5	1	0.02	0.004	0.00003	0.02
Pyridine	110-86-1	1	50	8	0.05	60
Tetrachloroethylene	127-18-4	1	30	10	0.09	40
Ethyl acetate	141-78-6	1	NA	NA	NA	NA
Xylenes (total)	1330-20-7	1	20	9	0.06	30

(continued)

Table 6-19 (continued)

Compound	CAS No.	Dermal hazard quotient or risk	Inhalation ratio for shower	Inhalation ratio for bathroom	Inhalation ratio for whole house	Oral ratio
Carbon tetrachloride	56-23-5	1.1E-04	7.E-03	1.E-02	8.E-02	9.3E-03
Ethyl ether	60-29-7	2.6E-03	NA	NA	NA	400
Methanol	67-56-1	1.1E-04	100	300	50000	9000
Acetone	67-64-1	1.0E-03	30	100	20000	1000
Butanol	71-36-3	5.4E-03	NA	NA	NA	200
Benzene	71-43-2	1.5E-05	1.E-02	2.E-02	2.E-01	6.6E-02
1,1,1-Trichloroethane	71-55-6	0.026	0.1	0.3	33	40
Methylene chloride	75-09-2	8.9E-07	2.E-01	4.E-01	3.E+00	1.1E+00
Carbon disulfide	75-15-0	0.035	0.1	0.2	25	30
Trichlorofluoromethane	75-69-4	0.018	0.1	0.2	25	60
Dichlorodifluoromethane	75-71-8	0.017	0.03	0.05	10	60
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	0.00036	3	10	1100	3000
Isobutyl alcohol	78-83-1	0.0015	NA	NA	NA	700
Methyl ethyl ketone	78-93-3	0.00036	0.5	3	500	3000
1,1,2-Trichloroethane	79-00-5	1.8E-05	8.E-03	2.E-02	1.E-01	5.6E-02
Trichloroethylene	79-01-6	1.0E-05	0.05	0.05	1	9.7E-02
2-Nitropropane	79-46-9	NA	1.E-04	1.E-04	3.E-03	NA
o-Xylene	95-47-6	0.009	NA	NA	NA	100
o-Cresol	95-48-7	0.088	NA	NA	NA	10
1,2-Dichlorobenzene	95-50-1	0.24	0.03	0.1	11	4
Nitrobenzene	98-95-3	3.9	0.003	0.01	2	0.3
Ethylbenzene	100-41-4	0.18	0.1	0.3	50	5
p-Cresol	106-44-5	0.82	NA	NA	NA	1
Methyl isobutyl ketone	108-10-1	0.0098	0.02	0.1	17	100
m-Xylene	108-38-3	0.01	NA	NA	NA	100
m-Cresol	108-39-4	0.085	NA	NA	NA	10
Toluene	108-88-3	0.053	0.05	0.1	17	20
Chlorobenzene	108-90-7	0.55	0.003	0.005	1	2
Cyclohexanone	108-94-1	0.00014	NA	NA	NA	7000
2-Ethoxyethanol	110-80-5	0.00026	50	300	33000	4000
Pyridine	110-86-1	0.39	0.02	0.1	20	3
Tetrachloroethylene	127-18-4	0.56	0.03	0.1	11	2
Ethyl acetate	141-78-6	0.00042	NA	NA	NA	2000
Xylenes (total)	1330-20-7	0.0096	0.05	0.1	17	100

NA = Not available.

Table 6-20. Concentrations in Well Water (mg/L)

Compound	CAS	CT-LQG		CT-SQG		SM-LQG		SM-SQG	
		Houston	Lincoln	Houston	Lincoln	Houston	Lincoln	Houston	Lincoln
Carbon tetrachloride	56-23-5	0.002	0.002	0.0005	0.0004	0.004	0.004	0.001	0.0009
Ethyl ether	60-29-7	0.4	0.4	0.1	0.1	0.8	0.9	0.2	0.2
Methanol	67-56-1	0.9	1	0.2	0.4	2	3	0.4	0.7
Acetone	67-64-1	0.7	1	0.2	0.3	1	2	0.4	0.6
Butanol	71-36-3	0.6	0.7	0.2	0.2	1	1	0.3	0.4
Benzene	71-43-2	0.03	0.03	0.008	0.008	0.07	0.07	0.02	0.02
1,1,1-Trichloroethane	71-55-6	0.004	0.003	0.001	0.0009	0.008	0.007	0.002	0.002
Methylene chloride	75-09-2	0.2	0.2	0.04	0.04	0.3	0.3	0.08	0.08
Carbon disulfide	75-15-0	0.05	0.05	0.01	0.01	0.1	0.1	0.03	0.03
Trichlorofluoromethane	75-69-4	0.003	0.002	0.0007	0.0006	0.005	0.005	0.001	0.001
Dichlorodifluoromethane	75-71-8	0.007	0.007	0.002	0.002	0.01	0.01	0.004	0.003
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	0.004	0.004	0.001	0.001	0.008	0.008	0.002	0.002
Isobutyl alcohol	78-83-1	0.7	0.8	0.2	0.2	1	2	0.4	0.4
Methyl ethyl ketone	78-93-3	0.8	1	0.2	0.3	2	2	0.4	0.6
1,1,2-Trichloroethane	79-00-5	0.01	0.01	0.003	0.003	0.02	0.02	0.006	0.006
Trichloroethylene	79-01-6	0.002	0.002	0.0006	0.0005	0.005	0.004	0.001	0.001
2-Nitropropane	79-46-9	0.2	0.2	0.05	0.04	0.4	0.4	0.09	0.09
o-Xylene	95-47-6	0.007	0.007	0.002	0.002	0.01	0.01	0.004	0.004
o-Cresol	95-48-7	0.05	0.05	0.01	0.01	0.1	0.1	0.03	0.03
1,2-Dichlorobenzene	95-50-1	0.0007	0.0007	0.0002	0.0002	0.002	0.001	0.0004	0.0004
Nitrobenzene	98-95-3	0.03	0.02	0.006	0.006	0.05	0.05	0.01	0.01
Ethylbenzene	100-41-4	0.005	0.005	0.001	0.001	0.01	0.01	0.003	0.003
p-Cresol	106-44-5	0.1	0.1	0.02	0.03	0.2	0.2	0.05	0.05
Methyl isobutyl ketone	108-10-1	0.3	0.4	0.08	0.1	0.7	0.8	0.2	0.2
m-Xylene	108-38-3	0.006	0.006	0.002	0.002	0.01	0.01	0.003	0.003
m-Cresol	108-39-4	0.08	0.08	0.02	0.02	0.2	0.2	0.04	0.04
Toluene	108-88-3	0.009	0.009	0.002	0.002	0.02	0.02	0.005	0.005
Chlorobenzene	108-90-7	0.003	0.003	0.0007	0.0007	0.006	0.006	0.002	0.001
Cyclohexanone	108-94-1	0.7	0.9	0.2	0.2	1	2	0.4	0.4
2-Ethoxyethanol	110-80-5	1	1	0.2	0.3	2	3	0.5	0.7
Pyridine	110-86-1	0.8	0.9	0.2	0.2	2	2	0.4	0.5
Tetrachloroethylene	127-18-4	0.002	0.002	0.0006	0.0005	0.005	0.004	0.001	0.001
Ethyl acetate	141-78-6	0.6	0.7	0.2	0.2	1	1	0.3	0.4
Xylenes (total)	1330-20-7	0.004	0.003	0.0009	0.0009	0.007	0.007	0.002	0.002

6.3 Postmodeling Risk Result Estimates

The risk results in this report represent a single facility which disposes a fixed number of wipes each day contaminated with a single solvent. This is not the way things are in the reality. Several facilities may dispose of various numbers of wipes contaminated with the same or different solvents in a single landfill. In order to estimate the risks from these more realistic scenarios the following method may be used. The risk estimations at a particular meteorologic location, landfill surface area, and fixed distance from the source are linear with respect to concentration in the landfill. For example, if the quantity of solvent on an individual wiper is assumed to be halved, the risk results are assumed to be halved as well, all other factors remaining constant. In order to adjust risk-based changes in some assumptions, these parameters must be assumed to be fixed in the risk adjustment calculation:

- Geographic location (Houston or Lincoln)
- Area of landfill (8,090 m² or 60,700 m²)
- Distance to receptor (75 m—air pathway, nationwide distribution to well (102m)—groundwater pathway).

If the previous assumptions are fixed, the following assumptions are linear factors and may be varied either singly or in groups. The factors that are linear in the air and groundwater pathway include:

- Weight of wipers (10.48 g each)
- Number of wipers per facility (30/SQG or 120/LQG)
- Number of facilities disposing in a single landfill (1 facility)
- Quantity of solvent assumed on each wipe (10.48 g = weight of wiper)
- Exposure duration for carcinogenic risks (does not apply to hazard quotient) (farmer 10 yr, child 7.3 yr)

Any of the factors enumerated above may be varied individually or together to reflect waste minimization efforts, multiple facilities disposing of wastes in a single landfill, and/or variable exposure durations for receptors.

6.3.1 Air Pathway Risks

Air pathway risks may be assumed to be linear and, as long as the maximum air concentration of vapors 75 m from a small or central tendency size landfill in Houston or Lincoln is considered to be the receptor, the linear parameters may be varied to produce a revised risk estimate.

6.3.2 Groundwater Pathway Risks

Groundwater risks have been estimated for both the ingestion and noningestion pathways. Any adjustment to the risk estimates must be performed for each pathway independently and the total risk summed at the completion of the estimation. Each pathway is addressed in the following sections.

6.3.2.1 Ingestion of Drinking Water Pathway

The risk associated with the ingestion of contaminated drinking water is very similar to the inhalation risk estimations. The groundwater ingestion risk estimations at a particular meteorologic location, landfill surface area, and fixed distance from the source are linear with respect to concentration in the landfill. The ingestion of groundwater pathway risks may be assumed to be linear and, as long as the receptor well is located at the same distance from a small or central tendency size landfill in Houston or Lincoln, the linear parameters may be varied to produce a revised risk estimate.

6.3.2.2 Noningestion Exposure to Contaminated Tap Water

The same parameters listed in the previous sections are assumed fixed and linear in these risk adjustment calculations also. The difference in the risk adjustment for these pathways is that each exposure must be adjusted independently and the risks summed after the adjustment. The adjustment to the risk may not be made to the total risk for the noningestion pathways. This means the inhalation risk must be adjusted individually for exposures in the following:

- Shower
- Bathroom
- Rest of the house.

Dermal exposures during bathing or showering must be adjusted independently as well.

The risk from each exposure pathway is assumed linear in the same way as the groundwater ingestion pathway and each pathway may be adjusted. The groundwater noningestion risk estimations at a particular meteorologic location, landfill surface area, and fixed distance from the source are linear with respect to concentration in the landfill. The risks may be assumed to be linear and, as long as the receptor well is located at the same distance from a small or central tendency size landfill in Houston or Lincoln, the linear parameters may be varied to produce a revised risk estimate (see Table 6-19).

6.4 Conclusions

The methodology presented in this section allows for the estimation of risk for a variety of waste disposal scenarios. Using the data generated for this risk assessment, one may address multiple management options for numerous types of wipers and shop towels. The use of different types of wipers can be reflected by adjusting the weight of the wiper and the quantity of solvent associated with that wiper. The number of wipers managed by a single facility may also be

adjusted either independently or together with the type of wiper. For example, a facility may generate fewer but heavier contaminated wipers that may contain an equal quantity of solvent. One may consider a scenario that reduces the quantity of solvent on each wiper by half or more through waste minimization efforts (e.g., centrifugation). In addition, one of the most likely scenarios is the disposal of wipers containing the same solvent by more than one facility in the same landfill. This may be readily addressed by this methodology.

6.5 Remaining Issues and Uncertainties

The remaining issues and uncertainties in this risk analysis include the simplifying assumptions used in this analysis. In performing this deterministic analysis, geographic locations were restricted to two sites that were thought to be high end and central tendency based on combined air and groundwater risk. However, previous risk assessment experience has shown that geographic location is not an especially sensitive parameter. A location that is extremely high for air emissions and dispersion (Phoenix) has no potential for leaching. Landfill sizes are confined to 10th and 50th percentile areas, which may or may not be appropriate for a high end for the groundwater pathway. For the groundwater pathway, the larger landfills frequently are high end because of lower estimated DAFs. One way to determine the appropriate high-end risks that considers all parameters is to perform a quantitative uncertainty analysis using a Monte Carlo approach. For the groundwater risk this could include a Monte Carlo analysis using the EPACMTP model. These procedures would be useful to quantify the uncertainty in the analysis; however, the estimates in this document are not outside the distribution of risks expected from a Monte Carlo analysis of these scenarios.

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Appendix A

Partitioning Models

Appendix A

Landfill Partitioning Model

A simple spreadsheet calculation model was used to determine the contaminant loss from a landfill due to degradation, volatilization, and leaching (run-off losses were assumed to be zero). The model assumes linear partitioning, first order rate losses, and uses a finite difference (numerical) integration approach to solve the mass balance equations. The model evaluates contaminant losses over three separate conditions. The first condition is the daily waste addition in which the waste is in direct contact with the atmosphere. The second condition is the active landfill cell in which the waste is covered by a thin "daily" cover. The third condition is the closed landfill cell in which the waste is covered by a thick landfill cap. The model tracks the average annual soil concentration and sums and tracks both the annual emissions and leaching rates for the user specified active life of the landfill (annual waste application) followed by 40 years of inactive use (i.e., closed landfill).

The model is limited in that it does not consider concentration profiles within the landfill and it does not allow for differences in the permeability (density, void fraction, and organic content) within or between the waste layer, the daily cover, and the landfill cap (i.e., the waste and waste covers are assumed to have the same transport properties by the model).

Model Theory

Equilibrium Partitioning

The total concentration of contaminant in the soil can be expressed as the sum of the masses of contaminant adsorbed on the soil or waste particles, dissolved in the liquid, and in the air spaces divided by the total mass of contaminated soil as follows:

$$C_T = C_s + \theta_w C_w / \rho_b + \theta_a C_a / \rho_b \quad (1)$$

where

- C_T = total contaminant concentration in landfill (mg/kg = g/Mg)
- C_s = concentration of contaminant adsorbed on soil (mg/kg = g/Mg)
- θ_w = water-filled soil porosity ($\text{m}^3_{\text{water}} / \text{m}^3_{\text{soil}}$)
- C_w = concentration of contaminant in liquid ($\mu\text{g}/\text{cm}^3 = \text{g}/\text{m}^3$)
- ρ_b = soil dry bulk density ($\text{g}/\text{cm}^3 = \text{Mg}/\text{m}^3$)
- θ_a = air-filled soil porosity ($\text{m}^3_{\text{air}} / \text{m}^3_{\text{soil}}$)
- C_a = concentration of contaminant in air ($\mu\text{g}/\text{cm}^3 = \text{g}/\text{m}^3$).

The adsorbed contaminant concentration is assumed to be linearly related to the liquid phase concentration as follows:

$$C_s = K_d C_w \quad (2)$$

where

K_d = soil-water partition coefficient ($\text{cm}^3/\text{g} = \text{m}^3/\text{Mg}$) = $K_{oc} f_{oc}$ for organic compounds
 K_{oc} = soil organic carbon partition coefficient (cm^3/g)
 f_{oc} = organic carbon content of soil (g/g).

The contaminant concentration in the vapor phase is assumed to be linearly related to the liquid phase concentration as follows:

$$C_a = H' C_w \quad (3)$$

where

H' = dimensionless Henry's Law constant = $41 \times H$
 H = Henry's Law constant at 25 °C ($\text{atm-m}^3/\text{mol}$).

Equations 2 and 3 assume linear equilibrium partitioning between the adsorbed contaminant, the dissolved contaminant and the volatilized contaminant. Combining Equations 1, 2, and 3 yields:

$$C_T = C_s [1 + \theta_w/(K_d \rho_b) + \theta_a H'/(K_d \rho_b)]. \quad (4)$$

The total contaminant concentration, C_T , represents the measured soil concentration. However, it is the adsorbed soil concentration that is needed to calculate the equilibrium liquid and air contaminant concentrations (Equations 2 and 3). Equation 4 can be rearranged to calculate the adsorbed soil contaminant concentration given the total contaminant concentration as follows:

$$C_s = \frac{C_T K_d \rho_b}{(K_d \rho_b + \theta_w + \theta_a H')} \quad (5)$$

Overall Mass Balance and Contaminant Half-life

For a constant volume system assuming first-order rate loss mechanisms, the mass balance can be expressed as:

$$(\delta C_T / \delta t) = -(k_{app,air} + k_{app,leach} + k_{app,runoff} + k_{app,bio} + k_{app,hyd}) C_T \quad (6)$$

where

$k_{app,air}$ = the apparent first order rate constant for volatilization, 1/sec
 $k_{app,leach}$ = the apparent first order rate constant for leaching, 1/sec
 $k_{app,runoff}$ = the apparent first order rate constant for rain run-off, 1/sec
 $k_{app,bio}$ = the apparent first order rate constant for biodegradation, 1/sec
 $k_{app,hyd}$ = the apparent first order rate constant for hydrolysis, 1/sec
 t = time, sec.

For small enough time steps (time steps in which C_T changes only a few percent), Equation 6 can be approximated as follows:

$$(M_{s,t+\Delta t} - M_{s,t})/(\Delta t) = - (k_{app,air} + k_{app,leach} + k_{app,runoff} + k_{app,bio} + k_{app,hyd}) M_{s,t} \quad (7)$$

or

$$\Delta M_{tot} = \Delta M_{air} + \Delta M_{leach} + \Delta M_{runoff} + \Delta M_{bio} + \Delta M_{hyd} \quad (8)$$

where

- $M_{s,t+\Delta t}$ = mass of contaminant in soil at time $t+\Delta t$, g
- $M_{s,t}$ = mass of contaminant in soil at time t , g
- Δt = time step of calculation, sec
- ΔM_{tot} = total mass of contaminant removed from soil over time step, g = $M_{s,t} - M_{s,t+\Delta t}$
- ΔM_{air} = mass of contaminant lost over time step due to volatilization, g
- ΔM_{leach} = mass of contaminant lost over time step due to leaching, g
- ΔM_{runoff} = mass of contaminant lost over time step due to run-off, g
- ΔM_{bio} = mass of contaminant lost over time step due to biodegradation, g
- ΔM_{hyd} = mass of contaminant lost over time step due to hydrolysis, g.

Due to the simplified nature of the numerical integration used, any number of competing loss mechanisms can be included in the model as each of the loss mechanisms can be evaluated separately and then summed together. The overall apparent first order disappearance rate is simply the sum of all of the individual first order rate constants.

$$k_{app,overall} = k_{app,air} + k_{app,leach} + k_{app,runoff} + k_{app,bio} + k_{app,hyd} \quad (9)$$

Unfortunately, there are few controlled biodegradation rate studies that actually measure biodegradation rates while accounting for competing removal mechanisms. What is typically reported in the literature is a contaminant disappearance rate (or half-life) in soil, which includes losses via volatilization, leaching and hydrolysis as well as biodegradation. That is, data for $k_{app,overall}$ are generally more prevalent than data specifically for $k_{app,bio}$. As a result, the model first calculates $k_{app,overall}$ from the soil half life and then integrates Equation 6 to calculate the total mass lost from the system as follows:

$$\Delta M_{tot} = M_{s,t} [1 - \exp(-k_{app,overall} \Delta t)] \quad (10)$$

The mass lost by each loss mechanism is then calculated, and $\Delta M_{bio} + \Delta M_{hyd}$ is calculated by difference. If ΔM_{tot} as calculated by Equation 10 is less than $\Delta M_{air} + \Delta M_{leach} + \Delta M_{runoff}$, then Equation 8 is used to calculate $\Delta M_{bio} + \Delta M_{hyd}$ by difference.

Mass Lost Via Volatilization

The primary mechanism of contaminant loss to the atmosphere is the diffusion of volatilized contaminant to the soil surface. During periods of evaporation, the flux of water vapor enhances contaminant transport to the soil surface. Consequently, the total contaminant flux to the atmosphere is:

$$J_{\text{air},t} = J_{\text{vol},t} + J_{\text{evaptr},t} \quad (11)$$

where

- $J_{\text{vol},t}$ = contaminant flux to the atmosphere due to diffusion, $\text{g/m}^2\text{-s}$
 $J_{\text{evaptr},t}$ = contaminant flux to the atmosphere due to evaporative transport, $\text{g/m}^2\text{-s}$.

As both leaching and enhanced volatilization due to evaporation losses were being modeled, the Jury model (Jury et al., 1983) was not used directly, as this solution, to be consistent with the model derivation, should calculate V_E based on the overall water flux, which would be a V_E term based on the infiltration rate. Instead, the losses were segregated, diffusional volatile losses were estimated for $V_E = 0$, leaching losses estimated assuming equilibrium concentration in the infiltrate, and the increased volatilization losses due to periods of evaporation were estimated using the terms from the Jury model solution that were primarily attributable to convective contaminant flux. This solution is an estimation methodology, but for small time steps, the solution is accurate as compared to the more complete set of Jury model equations.

Emissions With No Soil Cover

Assuming that there is no soil cover and no stagnant boundary air layer at the ground surface, and no net water flux ($V_E = 0$), the Jury et al. (1990) simplified finite source model for diffusional volatilization can be written as:

$$J_{\text{vol},t} = C_T \left(\frac{0.01 D_A}{\pi t} \right)^{1/2} \left[1 - \exp \left(\frac{-d_s^2}{0.04 D_A t} \right) \right] \quad (12)$$

where

- D_A = apparent diffusivity (cm^2/sec)
 π = 3.14
 t = time (sec)
 d_s = depth of uniform soil contamination at $t=0$, i.e., depth of daily addition (m);

and

$$D_A = \frac{\left(\theta_a^{\frac{10}{3}} D_i H + \theta_w^{\frac{10}{3}} D_w \right)}{n^2 (\rho_b K_d + \theta_w + \theta_a H)} \quad (13)$$

where

- n = total soil porosity ($L_{\text{pore}}/L_{\text{soil}} = 1 - (\rho_b/\rho_s)$)
 ρ_s = soil particle density (g/cm^3)
 D_i = diffusivity in air (cm^2/sec)
 D_w = diffusivity in water (cm^2/sec).

As discussed in Jury et al. (1984), volatilization with evaporation is a complex problem, but evaporation always increased the overall volatilization rate. Jury et al. (1984) presents an equation for the convection of contaminants caused by the flux of water in the soil. The convective volatilization flux caused by evaporation is then calculated by isolating the first half of the overall volatilization flux equation (Jury et al., 1983), which is the primary term for convective transport. The other terms are nearly identical to Equation 12, and approach Equation 12 in the limits of small time or small convective velocity. The evaporative flux was therefore estimated as follows:

$$J_{\text{evaptr},t} = \frac{1}{2} C_T \rho_b (0.01 V_E) \left[\text{erfc} \left(\frac{V_E t}{(4 D_A t)^{1/2}} \right) - \text{erfc} \left(\frac{(100 d_s + V_E t)}{(4 D_A t)^{1/2}} \right) \right] \quad (14)$$

where

V_E = evaporative convective velocity (cm/sec)
 $\text{erfc}(x)$ = complementary error function;

and

$$V_E = \left(\frac{-E}{(365 \times 24 \times 3600) \times (\rho_b K_d + \theta_w + \theta_a H)} \right) \quad (15)$$

where

E = average annual evaporation rate (cm/yr).

[Note: the minus sign is introduced because upward movement is in the negative direction.]

The total mass loss to the air can be calculated as follows:

$$\Delta M_{\text{air}} = (J_{\text{evaptr},t} + J_{\text{vol},t})(A \Delta t). \quad (16)$$

where

A = area of contaminant source, m^2 .

Emissions With Soil Cover

Jury et al. (1990) also provided simplified equations for the volatilization flux for a contaminated soil (waste) layer buried below a clean layer of soil. This method basically is to evaluate the contaminant flux for the depth of the system (contaminated layer + cover), then subtract out the flux attributable to the top layer (i.e., the flux assuming contaminant is present only in the cap). The volatilization contaminant flux for buried waste is then:

$$J_{\text{vol},t} = C_T \left(\frac{0.01 D_A}{\pi t} \right)^{1/2} \left[\exp \left(\frac{-d_{\text{cover}}^2}{0.04 D_A t} \right) - \exp \left(\frac{-(d_{\text{cover}} + d_s)^2}{0.04 D_A t} \right) \right] \quad (17)$$

where

d_{cover} = depth of daily soil cover or landfill cap, m.

Using the same rationale, the evaporative contaminant flux is equal to the contaminant flux assuming the entire system contains contaminant and subtracting out the emissions attributable to the top soil layer. The evaporative contaminant flux is then:

$$J_{\text{evap},t} = \frac{1}{2} C_T \rho_b (0.01 V_E) \left[\operatorname{erfc} \left(\frac{100 d_{\text{cover}} + V_E t}{(4 D_A t)^{1/2}} \right) - \operatorname{erfc} \left(\frac{100 (d_{\text{cover}} + d_s) + V_E t}{(4 D_A t)^{1/2}} \right) \right] \quad (18)$$

Mass Lost Via Leaching

The mass flux loss of a contaminant due to leaching is estimated by assuming the leachate is in equilibrium with the soil (i.e., Equation 2 applies).

$$J_{\text{leach},t} = \frac{C_T \rho_b (0.01 V_L)}{(\rho_b K_d + \theta_w + \theta_a H')} \quad (19)$$

where

- $J_{\text{leach},t}$ = contaminant flux in leachate at time t , $\text{g/m}^2\text{-s}$
- $V_L = (P + I - R - E)/(365 \times 24 \times 3600)$ = leachate rate (cm/sec)
- P = annual average precipitation rate (cm/yr)
- I = annual average irrigation rate (cm/yr)
- R = annual average runoff rate (cm/yr).

In the same fashion that the air fluxes were converted a mass loss, the leaching flux rate can be converted to a mass loss as follows:

$$\Delta M_{\text{leach}} = (J_{\text{leach},t})(A \Delta t). \quad (20)$$

Model Application for Landfill

The waste added to the landfill is assumed to be homogeneous and temporally consistent. One landfill cell is assumed to be filled per year. The user inputs the annual waste quantity and the contaminant concentration of the waste of interest, the waste density, the dimensions of the entire landfill, and the life expectancy of (i.e., number of cells in) the landfill. From this information, the dilution effect of the waste added to the landfill can be calculated. For example, the average contaminant concentration of a daily waste addition is calculated as follows:

$$C_T = \frac{\left(\frac{C_{waste} \times Q_{waste}}{N_{daily}} \right)}{\rho_b \times A_{daily} \times d_{daily}}$$

where

- C_{waste} = concentration of contaminant in waste (mg/kg = g/Mg)
- Q_{waste} = annual waste disposal rate (Mg/yr)
- N_{daily} = number of daily additions per year
- A_{daily} = area of a daily waste addition, m²
- d_{daily} = depth of a daily waste addition, m.

The landfill partitioning model equations are applied in three distinct compartments or time periods. These are: the daily waste addition in which the waste is in direct contact with the atmosphere; the active landfill cell in which the waste is covered by a thin "daily" cover; and the closed landfill cell in which the waste is covered by a thick landfill cap.

Losses from the uncovered daily waste addition are calculated for a user specified time (model runs were made using an uncovered duration of 12 hours). The dimensions of the daily waste addition is specified by the number of operating days and the number of "layers" used to fill the landfill cell. It was assumed that a daily waste addition was 2.5 feet deep and that there were 350 operating days per year. The amount of contaminant lost during the uncovered duration is calculated and the total contaminant concentration remaining in the waste is calculated as the starting concentration for the covered daily waste addition.

Losses from the covered daily addition are calculated over the time period when the waste is first covered until another daily addition is added on top of the waste. It is assumed that the entire first layer of the landfill cell is filled with sequential daily additions, then the second layer is filled in the same order as the first layer, and so on. Once waste is added on top of a daily addition "daily cell", it is assumed that the losses from that "daily cell" are minimal. Assuming that there are six waste layers, the time of exposure (i.e., time before more waste is added on top of the waste) for a given daily cell is, on average, 365/6 or 61 days. The total amount of contaminant emitted and leached over the 61 days is estimated by the model for a given daily quantity by adding losses from 12 hours of uncovered waste to the losses calculated for the covered daily cell. It is assumed that all daily waste additions have the same contaminant losses, so that the emissions and leaching estimates from one daily cell can be multiplied by the number of daily additions (350 operating days) to yield annual amounts of contaminant emitted and leached from the active landfill cell. The total amount of contaminant remaining in the landfill is also calculated to estimate the average starting contaminant concentration for the closed (capped) landfill cell.

The annual losses from a single capped landfill cell (closed landfill) are estimated over a 100 year period and then used to project the annual losses for the entire landfill. During the active life of the landfill, there is always one active landfill cell. However, the number of closed landfill cells increases sequentially until the entire landfill is filled. For example, in Year 1, there are

losses from an active landfill cell only (estimated from the daily waste additions). In Year 2, there are losses from an active landfill cell plus losses from the first year of the closed landfill cell simulation. In Year 3, there are losses from an active landfill cell plus both the first year losses of a closed landfill cell (the cell capped at end of Year 2) and the second year losses from a closed landfill cell (the cell capped at end of Year 1), and so on. In this manner, the annual losses from the entire landfill can be simulated from the annual losses of an active cell and a single capped cell. At the end of the active life of the landfill, emissions are projected from only the closed landfill simulation. That is, for a landfill with a 20-year life (20 cells), the losses projected for Year 21 are the sum of the annual losses for the closed landfill cell for Years 1 through Year 20, inclusive. The losses projected for Year 22 are the sum of the annual losses for the closed landfill cell for Years 2 through Year 21, and so on.

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Appendix B

Dispersion Modeling

Appendix B

Dispersion Modeling

Dispersion describes the transport of chemical emissions through the air to a receptor. In this risk analysis, dispersion modeling was used to estimate air concentrations associated with a unit emission ($1 \mu\text{g}/\text{m}^2\text{-s}$) (unitized air concentrations, or UACs) at a variety of potential receptor locations. The following sections discuss model selection, the critical parameters of the model, and the model results or UACs.

B.1 Model Selection

A number of dispersion models are available on the EPA Support Center for Regulatory Air Models (SCRAM) Bulletin Board (<http://www.epa.gov/scram001/>). These dispersion models were developed for a variety of applications and each has its own strengths and weaknesses. This analysis required a model with the capability to model dispersion of vapors and particulates from landfills, land application units, wastepiles, and tanks to receptors both on- and offsite for chronic, subchronic, and acute averaging times. Therefore, a dispersion model was needed that could model (1) area sources; (2) ground-level and elevated sources; (3) onsite and offsite impacts; (4) vapors and particulates; and (5) annual, monthly, and daily averaging times.

Five models were considered for this analysis:

- Industrial Source Complex - Short Term v.3 (ISCST3) - U.S. EPA, 1995
- Industrial Source Complex - Long Term v.3 (ISCLT3) - U.S. EPA, 1995
- Toxic Modeling System - Short Term (TOXST) - U.S. EPA, 1994c
- Fugitive Dust Model (FDM) - U.S. EPA, 1992
- COMPDEP - U.S. EPA, 1990.

Table B-1 summarizes the capabilities of these commonly used air dispersion models with respect to the requirements of this analysis. The ISCST3 (U.S. EPA, 1995) was selected for all aspects of this analysis because it met all the criteria. This model, however, has considerable run times, which limited the number of meteorological stations included in this analysis.

B.2 Critical Parameters

This section discusses the critical parameters of the selected model, ISCST3, and the results of sensitivity analyses performed to investigate several of the model parameters. Results of the sensitivity analyses are presented in Appendix F of *Air Characteristic Study, Volume II, Technical Background Document* (U.S. EPA, 1998).

Table B-1. Air Dispersion Model Capabilities

Model	Source Geometry	Source Height		Receptor Location		Chemical Phase		Averaging Period		
	Area Source	Elevated	Ground	Onsite Air Conc.	Offsite Air Conc.	Vapor	Particulate	Annual	Monthly	Daily
ISCST3	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ISCLT3	✓	✓	✓	✓	✓	✓	✓	✓		
TOXST	✓	✓	✓		✓	✓	✓	✓	✓	✓
FDM	✓	✓	^a	✓	✓		✓	✓		✓
COMPDEP		✓			✓	✓	✓	✓		✓

^a Minimum height of source for modeling is 0.5 meters.

B.2.1 General Assumptions

This section discusses depletion, rural vs. urban, and terrain assumptions.

B.2.1.1 Depletion. Air concentrations can be calculated in ISCST3 with or without wet and dry depletion. Modeled concentrations without depletions are higher than those with depletions. A sensitivity analysis was conducted that showed that the differences in the maximum concentrations with depletion and without depletion are small at close-to-source receptors, increasing only slightly as the distance from the source increases. The sensitivity analysis also shows that the run time for calculating concentrations using the ISCST3 model with depletion options is 15 to 30 times longer than the run time without depletions for the 5th and 95th percentile of the sizes of land application units. (The difference is greater for larger sources; see sensitivity analysis in Appendix of U.S. EPA, 1998.) Therefore, concentrations were calculated without depletions in this analysis so that a greater number of meteorological locations could be modeled in the time available.

Assumptions Made for Dispersion Modeling

- Dry and wet depletion options were not activated in the dispersion modeling.
- The rural option was used in the dispersion modeling since the types of WMUs being assessed are typically in nonurban areas.
- Flat terrain was assumed.
- An area source was modeled for all WMUs.
- To minimize error due to site orientation, a square area source with sides parallel to X- and Y- axes was modeled.
- Receptor points were placed on 0, 25, 50, 75, 150, 500, and 1,000 m receptor squares starting from the edge of the source with 16 receptor points on each square.
- Modeling was conducted using a unit emission rate of 1 $\mu\text{g/s-m}^2$.

B.2.1.2 Rural vs. Urban. ISCST3 may be run in rural or urban mode, depending on land use within a 3-km radius from the source. These modes differ with respect to wind profile exponent and potential temperature gradients. Unless the site is located in a heavily metropolitan

area, the rural option is generally more appropriate. Because the types of WMUs being assessed are typically in nonurban areas, the rural option was used in this analysis.

B.2.1.3 Terrain. Flat terrain for both the source and the surrounding area was assumed in the modeling analysis for two reasons: (1) ISCST3 models all area sources as flat, and (2) complex terrain simulations in the surrounding area result in air concentrations that are highly dependent upon site-specific topography. A specific WMU's location in relation to a hill or valley produces results that would not be applicable to other locations. Complex terrain applications are extremely site-specific; therefore, model calculations from one particular complex terrain location cannot be applied to another. Conversely, simulations from flat terrain produce values that are more universally applicable.

B.2.2 Meteorological Stations and Data

Meteorological data at over 200 meteorological stations in the United States are available on the SCRAM Bulletin Board (<http://www.epa.gov/scram001>) and from a number of other sources. A set of 29 meteorological stations selected in an assessment for EPA's Superfund program Soil Screening Levels (SSLs) (EQM, 1993) as being representative of the nine general climate regions of the continental United States was used in this analysis.

In EPA's SSL study, it was determined that 29 meteorological stations would be a sufficient sample to represent the population of 200 meteorological stations and predict mean dispersion values with a high (95 percent) degree of confidence. The 29 meteorological stations were distributed among nine climate regions based on meteorological representativeness and variability across each region.

These climate regions were:

- North Pacific Coastal
- Northwest Mountains
- Midwest
- South Pacific Coastal
- Central Plains
- Northern Atlantic
- Southwest
- Southeast
- South Florida.

Large-scale regional average conditions were used to select the actual stations (EQM, 1993).

The 29 meteorological stations are listed in Table B-2. To assign each Industrial D facility to a meteorological station, EPA used a Geographic Information System (GIS) to construct Thiessen polygons around each station that enclose the areas closest to each station. The boundaries of these areas were then adjusted to ensure that each boundary encloses an area that is most similar in meteorological conditions to those measured at the meteorological station. To assist in this process, a GIS coverage of Bailey's ecoregion divisions and provinces (Bailey et al., 1994) was used to conflate the boundaries to correspond to physiographic features likely to influence climate or boundaries corresponding to changes in temperature or precipitation. General wind regimes were also considered in the conflation process.

Key factors considered in the conflation process include: defining coastal regimes as narrow polygons, which generally stretched about 25 to 50 miles inland, to capture regions

Table B-2. Meteorological Stations Used in the Air Characteristic Study

City	Met Station		Latitude		Longitude	
	State	#	Degree	Minute	Degree	Minute
Albuquerque	NM	23050	35	3	106	37
Atlanta	GA	13874	33	39	84	25
Bismarck	ND	24011	46	46	100	45
Boise	ID	24131	43	34	116	13
Casper	WY	24089	42	55	106	28
Charleston	SC	13880	32	54	80	2
Chicago	IL	94846	41	59	87	54
Cleveland	OH	14820	41	25	81	52
Denver	CO	23062	39	46	104	52
Fresno	CA	93193	36	46	119	43
Harrisburg	PA	14751	40	13	76	51
Hartford	CT	14740	41	56	72	41
Houston	TX	12960	29	58	95	21
Huntington	WV	03860	38	22	82	33
Las Vegas	NV	23169	36	5	115	10
Lincoln	NE	14939	40	51	96	45
Little Rock	AR	13963	34	44	92	14
Los Angeles	CA	23174	33	56	118	24
Miami	FL	12839	25	49	80	17
Minneapolis	MN	14922	44	53	93	13
Philadelphia	PA	13739	39	53	75	15
Phoenix	AZ	23183	33	26	112	1
Portland	ME	14764	43	39	70	19
Raleigh-Durham	NC	13722	35	52	78	47
Salem	OR	24232	44	55	123	0
Salt Lake City	UT	24127	40	47	111	57
San Francisco	CA	23234	37	37	122	23
Seattle	WA	24233	47	27	122	18
Winnemucca	NV	24128	40	54	117	48

Source: EQM (1993).

dominated by coastal climate effects; maintaining tropical/subtropical and arid/semiarid divisions in the southwestern United States; and using the ecoregion boundaries in Washington, Oregon, and California to separate the more humid marine/redwood or Mediterranean mountain regimes from the deserts to the east. In general, Thiessen polygons were used to define the meteorological station areas for the remainder of the country.

Based on facility locations derived from Industrial D survey data, the Industrial D sites were then overlaid on the GIS coverage of the conflated meteorological boundaries and meteorological station assignments were then exported for use in the modeling exercise. Four sites in Alaska and four in Hawaii were deleted from the analysis at this point because the 29 meteorological stations are limited to the continental United States. Figure B-1 shows the final

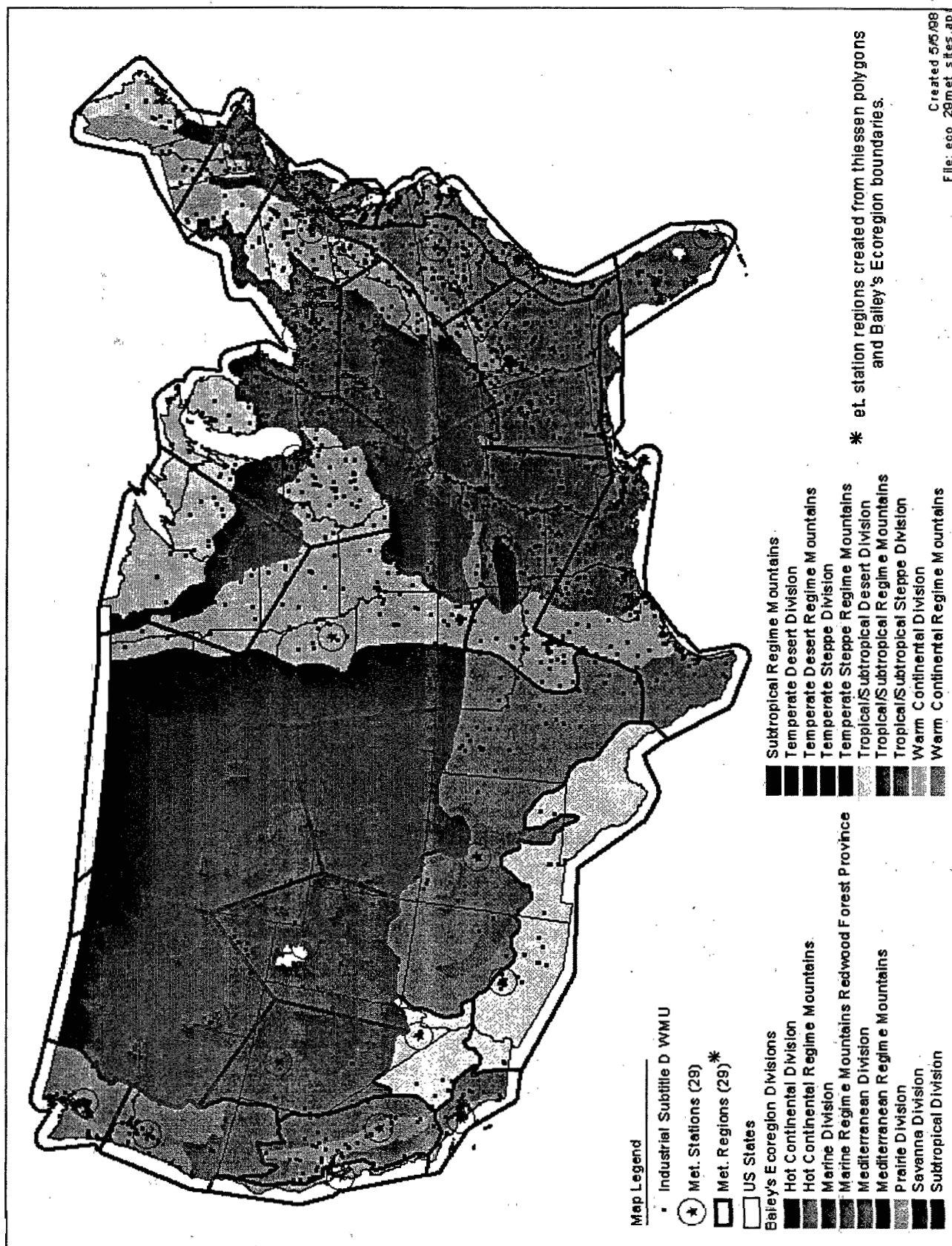


Figure B-1. Meteorological station regions.

meteorological station boundaries used for the study along with the locations of the Industrial D facility sites.

The modeling analysis was conducted using 5 years of representative meteorological data from each of the 29 meteorological stations. Five-year wind roses representing the frequency of wind directions and windspeeds for the 29 meteorological stations were analyzed. These show that the 29 meteorological stations represent a variety of wind patterns and are presented in Appendix F of U.S. EPA, 1998.

**Shape of Wind Rose for
29 Meteorological Stations**

Shape of Wind Rose	No. of Stations
Narrowly distributed	10
Moderately distributed	4
Evenly distributed	6
Bimodally distributed	9

**Meteorological Data for
the ISCST3 Model
without Depletion**

Wind Direction (or Flow Vector)
Windspeed
Ambient Temperature
Stability Class
Mixing Height

Wind direction and windspeed are typically the most important meteorological inputs for dispersion modeling analysis. Wind direction determines the direction of the greatest impacts. Windspeed is inversely proportional to ground-level air concentrations, so that the lower the windspeed, the higher the air concentration.

Mixing height determines the heights to which pollutants can be diffused vertically. Stability class is also an important factor in determining the rate of lateral and vertical diffusion. The more unstable the air, the greater the diffusion. This increase would lower centerline concentration.

B.2.3 Source Release Parameters

This section describes the source parameters and assumptions used in the dispersion modeling, including source type and elevation, source shape and orientation, and source areas.

B.2.3.1 Source Type and Elevation. All WMU types modeled in this analysis were modeled as area sources. Landfills and land application units were modeled as ground-level sources, and wastepiles and tanks were modeled as elevated sources.

B.2.3.2 Source Shape and Orientation. The ISCST3 models an area source as a rectangle or combination of rectangles. The user may also specify an angle of rotation relative to a north-south orientation. A sensitivity analysis was conducted to compare the air concentrations from a square area source, a rectangular area source oriented east to west, and a rectangular area source oriented north to south to determine what role source shape and orientation play in determining dispersion coefficients of air pollutants. The results show that the differences in unitized air concentration between the square area source and the two rectangular area sources are less than the differences between the two rectangular sources. In addition, a square area

source has the least amount of impact on orientation. Because information on source shapes or orientations is not available, a square source was chosen to minimize the errors caused by source shapes and orientations. (See sensitivity analysis in Appendix F of U.S. EPA, 1998, for details.)

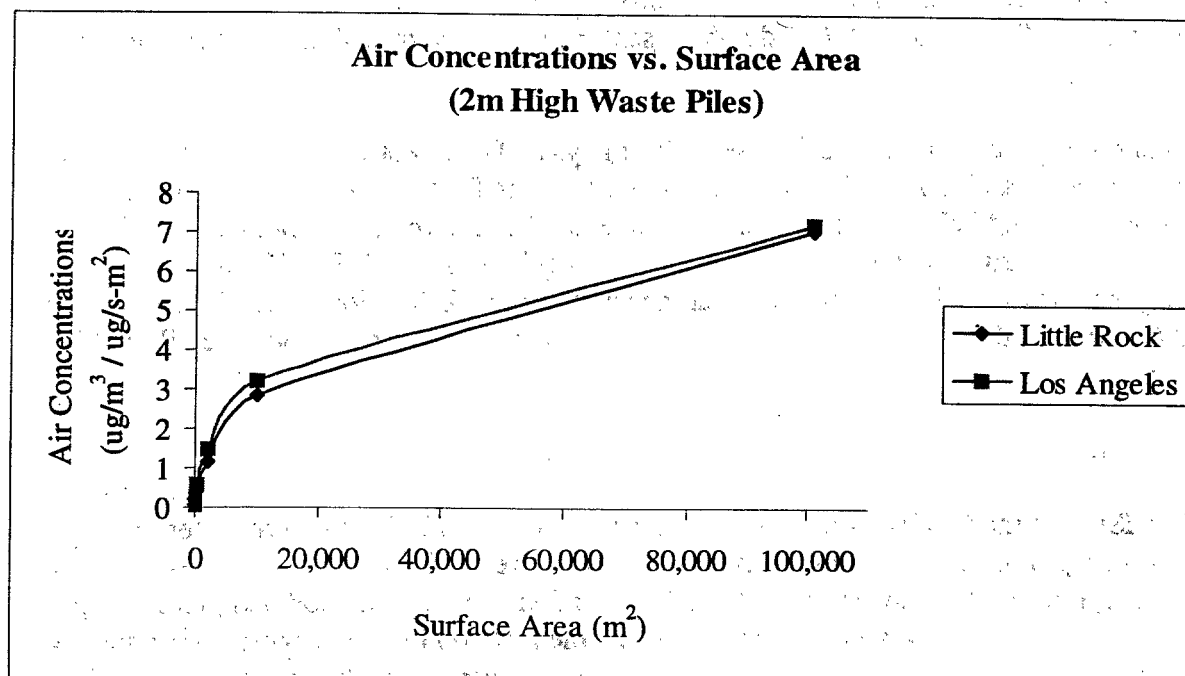
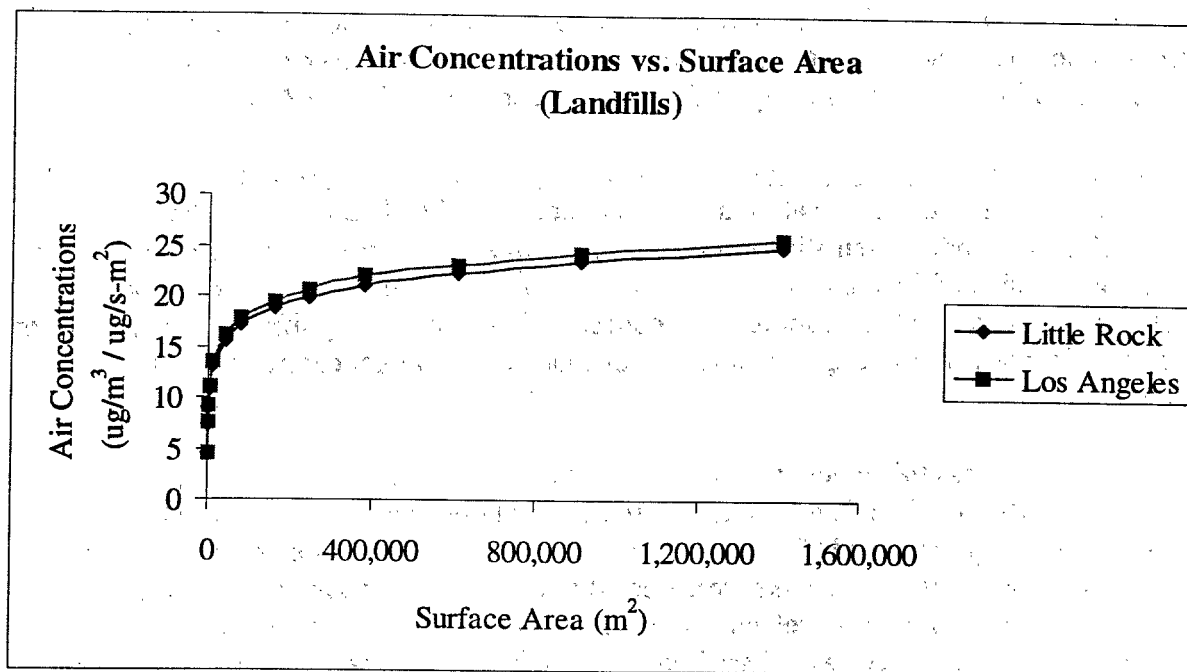
B.2.3.3 Source Areas Modeled. In the modeling analysis, five types of WMUs were considered (i.e., landfill, land application unit, wastepile, aerated tank, and storage tank). Because the ISCST3 model is sensitive to the size of the area source, the relationship between air concentrations and size of the area source was analyzed. As illustrated in Figure B-2, the results show that, for relatively small area sources, air concentrations increase significantly as the size of the area source increases. For large area sources, this increase in air concentrations is not as significant.

In order to address this model sensitivity, yet avoid modeling approximately 2,000 separate WMUs, EPA developed area strata that represented the distribution of the surface area for each of the WMU types. Landfills and land application units were modeled as ground-level area sources, while wastepiles and tanks were treated as elevated area sources. Separate area strata were developed for ground-level and elevated sources. In addition, separate areas were modeled for tanks, because these were based on model units, rather than the Industrial D Survey database. Fourteen area strata were selected for landfills and land application units, seven for wastepiles, and two for tanks. The median area size for each stratum was used in the dispersion modeling analysis. Tables B-3, B-4, and B-5 present the source areas and heights used in the modeling analysis.

This provided a set of UACs for use in the analysis. For any specific WMU, a UAC was then estimated using an interpolation routine that used the UACs associated with modeled areas immediately above and below the actual area of the unit. The interpolation routine provides a technique for minimizing the number of ISCST3 runs required for a WMU while also minimizing the error associated with the difference between the UACs for preselected areas and the UAC for the actual area of the WMU. The interpolation is described in more detail in U.S. EPA (1998).

B.2.4 Receptors

The ISCST3 model allows the user to specify receptors with Cartesian receptor grid and/or polar receptor grid. In general, Cartesian receptors are used for near-source receptors and polar grid receptors for more distant receptors. The number of receptors modeled greatly impacts run time. However, if too few receptors are modeled, the location of peak concentration may be missed. A sensitivity analysis was conducted to determine receptor locations and spacings that would provide adequate resolution without modeling an excessive number of receptors. (See Appendix F of U.S. EPA, 1998, for details.) The results of the sensitivity analysis show that the maximum concentrations are generally higher for a dense receptor grid (i.e., 64 or 32 receptors on each square) than for a scattered receptor grid (i.e., 16 receptors on each square). However, the differences of the maximum receptor concentrations are not significant between a dense and a scattered receptor grid. Therefore, 16 evenly spaced receptor points on each square were used in the modeling. The sensitivity analysis also shows that the maximum downwind concentrations



Note: Largest areas modeled for each WMU type have been omitted from the chart to improve clarity.

Figure B-2. Air concentration vs. size of area source.

Table B-3. Areas Modeled for Landfills and Land Application Units

Source Area (m ²)	Source Height (m)
81	0
567	0
1,551	0
4,047	0
12,546	0
40,500	0
78,957	0
161,880	0
243,000	0
376,776	0
607,000	0
906,528	0
1,408,356	0
8,090,000	0

Table B-4. Areas and Source Heights Modeled for Wastepiles

Source Area (m ²)	Source Heights (m)	
20	2	5
162	2	5
486	2	5
2,100	2	5
10,100	2	5
101,000	2	5
1,300,000	2	5

Table B-5. Areas Modeled for Aerated and Storage Tanks

Source Area (m ²)	Source Height (m)
27	4.0
430	3.7

decrease sharply from the edge of the area source to about 1,000 meters from the source. After the first 1,000 meters from the edge of the area source, concentrations decrease very slowly as the downwind distance increases. Therefore, for annual average concentrations, the receptor points were placed on 0, 25, 50, 75, 150, 500, and 1,000 meter receptor squares starting from the edge of the source, with 16 receptor points on each square. The first receptor square (i.e., 0 meter) is at the edge of the unit. For monthly and daily averaging periods used in the subchronic and acute assessment, the receptors were placed on 0, 25, 50, and 75 meter receptor squares.

B.3 Unitized Air Concentrations

Unitized air concentrations (UACs) were calculated by running ISCST3 with a unit emission rate (i.e., $1 \mu\text{g}/\text{m}^2\text{-s}$). The selected areas for each type of WMU were modeled with 29 representative meteorological locations in the continental United States to estimate UACs. The 5-year average UACs at all receptor points were calculated for the long-term or chronic exposure scenario. They were used as inputs to the Monte Carlo analysis and as input to the interpolation routine discussed above.

A similar methodology and assumptions were used to model dispersion for acute and subchronic exposures. Since the ISCST3 model uses hourly meteorological data, the outputs from the model can be used to develop any averaging times equal to or greater than 1 hour. One set of ISCST3 runs (for the 21 areas and 29 meteorological stations) was done for both acute and subchronic, resulting in 5 years of hourly average concentrations at each receptor. For each area, meteorological location, and receptor location, the maximum air concentration for any 24-hour period over the 5 years was selected. Then, for each area and meteorological station, the maximum 24-hour air concentration among all receptor locations at each distance modeled was selected, and this was used as the UAC for that area and meteorological station for acute exposure. The same method was used to determine the subchronic UAC, except that the maximum 30-day period over the 5 years was used instead of the maximum 24-hour period. It was assumed that the greatest risk of acute exposure would be closest to the site; therefore, the receptors points were placed at 0, 25, 50, and 75 meters from the edge of the WMU, with 16 equally spaced directions at each distance.

The maximum annual average UACs are presented in Tables B-6 through B-8 for the different types of WMUs. Typically, the location of maximum impacts with respect to the source are determined by the prevailing wind direction. For ground-level area sources (i.e., landfills and land application units), maximum annual average UACs are always located on the first receptor square (i.e., 0-m receptors or onsite receptors). For elevated area sources, the maximum annual average UACs are usually located on the first receptor square and occasionally located on the second or third receptor square. The results in Tables B-6 through B-8 show that the annual average UACs increase with the increasing area size of the sources.

Figures B-3 through B-6 show that maximum UACs vary with meteorological location. For landfills and land application units, the maximum UACs at some meteorological locations can be twice as much as those at other locations. For wastepiles and tanks, the maximum UACs at some meteorological locations are more than twice those at other meteorological locations.

Table B-6. Maximum Annual Average Unitized Air Concentrations ($\mu\text{g}/\text{m}^3$ / $\mu\text{g}/\text{s}\cdot\text{m}^3$) for Landfills and Land Application Units

Met Station	Station No.	Area (m^2)														
		81	567	1,551	4,047	12,546	40,500	78,957	161,880	243,000	376,776	607,000	906,529	1,408,356	8,090,000	
Albuquerque, NM	23050	3,521	5,791	7,103	8,450	10,175	12,112	13,316	14,535	15,487	16,406	17,299	18,206	19,287	25,002	
Atlanta, GA	13874	3,919	6,369	7,789	9,236	11,119	13,224	14,526	15,927	16,902	17,896	18,937	19,950	21,142	27,323	
Bismarck, ND	24011	3,598	5,871	7,182	8,528	10,273	12,231	13,443	14,816	15,650	16,579	17,620	18,566	19,667	25,220	
Boise, ID	24131	4,806	7,739	9,458	11,251	13,543	16,138	17,770	19,508	20,710	21,978	23,311	24,550	26,052	33,867	
Casper, WY	24089	3,532	5,718	6,980	8,265	9,923	11,790	12,931	14,184	15,020	15,892	16,833	17,724	18,751	24,085	
Charleston, SC	13880	3,760	6,134	7,503	8,907	10,733	12,778	14,045	15,392	16,350	17,320	18,316	19,302	20,451	26,415	
Chicago, IL	94846	3,678	6,011	7,356	8,726	10,505	12,493	13,712	14,980	15,944	16,871	17,797	18,741	19,843	25,626	
Cleveland, OH	14820	4,163	6,639	8,064	9,519	11,415	13,527	14,833	16,268	17,227	18,232	19,308	20,341	21,564	27,959	
Denver, CO	23062	5,364	8,645	10,541	12,488	15,039	17,898	19,690	21,634	22,945	24,336	25,798	27,217	28,886	37,541	
Fresno, CA	93193	5,783	9,460	11,587	13,794	16,611	19,800	21,792	24,024	25,383	26,916	28,634	30,144	31,955	41,022	
Harrisburg, PA	14751	4,291	6,892	8,380	9,900	11,877	14,073	15,434	16,882	17,900	18,937	20,006	21,060	22,298	28,745	
Hartford, CT	14740	4,478	7,454	9,176	10,934	13,216	15,775	17,344	18,848	20,221	21,412	22,470	23,584	25,101	32,702	
Houston, TX	12960	4,137	6,811	8,352	9,925	11,961	14,239	15,632	17,227	18,189	19,244	20,448	21,531	22,784	28,985	
Huntington, WV	3860	5,548	9,154	11,240	13,378	16,161	19,282	21,207	23,265	24,728	26,197	27,720	29,218	30,966	39,932	
Las Vegas, NV	23169	4,353	7,072	8,645	10,254	12,349	14,700	16,159	17,697	18,816	19,941	21,081	22,222	23,557	30,668	
Lincoln, NE	14939	3,007	4,867	5,936	7,027	8,445	10,027	11,000	12,036	12,781	13,525	14,291	15,051	15,939	20,577	
Little Rock, AR	13963	4,500	7,402	9,079	10,795	13,023	15,528	17,065	18,732	19,883	21,053	22,296	23,486	24,888	32,110	
Los Angeles, CA	24174	4,492	7,480	9,269	11,100	13,457	16,112	17,745	19,332	20,709	21,944	23,083	24,311	25,753	33,445	
Miami, FL	12839	3,752	6,150	7,550	8,984	10,845	12,944	14,240	15,718	16,612	17,608	18,731	19,750	20,932	26,829	
Minneapolis, MN	14922	3,334	5,453	6,676	7,924	9,541	11,354	12,464	13,676	14,502	15,347	16,253	17,121	18,127	23,300	
Philadelphia, PA	13739	4,359	7,076	8,643	10,243	12,317	14,644	16,076	17,596	18,689	19,784	20,908	22,021	23,317	30,083	
Phoenix, AZ	23183	5,640	9,043	11,002	13,016	15,650	18,591	20,439	22,494	23,763	25,185	26,729	28,164	29,850	30,083	
Portland, ME	14764	5,028	8,269	10,146	12,070	14,574	17,389	19,127	20,946	22,310	23,642	24,983	26,344	27,933	36,239	
Raleigh-Durham, NC	13722	4,407	7,196	8,805	10,453	12,599	14,999	16,483	18,079	19,192	20,327	21,510	22,665	24,018	30,956	
Salem, OR	24232	4,580	7,348	8,939	10,567	12,687	15,053	18,120	18,120	19,185	20,308	21,513	22,661	24,005	31,007	
Salt Lake City, UT	24127	4,735	7,576	9,218	10,909	13,095	15,546	18,754	18,754	19,865	21,050	22,318	23,521	24,956	32,412	
San Francisco, CA	23234	4,500	7,257	8,842	10,465	12,585	14,946	17,977	17,977	19,084	20,213	21,376	22,524	23,882	30,988	
Seattle, WA	24233	4,276	6,799	8,231	9,691	11,592	13,686	16,390	16,390	17,324	18,310	19,359	20,365	21,547	27,722	
Winnemucca, NV	24128	4,123	6,720	8,222	9,763	11,772	14,028	16,889	16,889	17,980	19,055	20,130	21,224	22,505	29,215	

Table B-7. Maximum Annual Average Unitized Air Concentrations ($\mu\text{g}/\text{m}^3 / \mu\text{g}/\text{s}\cdot\text{m}^2$) for Wastepiles

Station		Area (m ²) (2-m Height Wastepiles)						Area Strata (m ²) (5-m Height Wastepiles)							
Met Station	No.	20	162	486	2,100	10,100	101,000	1,300,000	20	162	486	2,100	10,100	101,000	1,300,000
Albuquerque, NM	23050	0.037	0.171	0.378	0.993	2.359	5.704	11.011	0.014	0.053	0.107	0.288	0.824	2.956	7.671
Atlanta, GA	13874	0.043	0.195	0.431	1.141	2.644	6.284	12.066	0.016	0.060	0.120	0.325	0.940	3.312	8.467
Bismarck, ND	24011	0.035	0.155	0.343	0.932	2.273	5.685	11.093	0.013	0.049	0.097	0.258	0.759	2.867	7.693
Boise, ID	24131	0.056	0.235	0.520	1.389	3.183	7.621	14.732	0.021	0.072	0.143	0.384	1.132	3.996	10.383
Casper, WY	24089	0.040	0.181	0.405	1.084	2.461	5.714	10.846	0.015	0.056	0.110	0.301	0.894	3.080	7.678
Charleston, SC	13880	0.038	0.168	0.372	1.003	2.393	5.944	11.581	0.014	0.053	0.105	0.280	0.820	3.008	8.027
Chicago, IL	94846	0.038	0.170	0.380	1.030	2.431	5.897	11.340	0.014	0.053	0.106	0.285	0.845	3.049	7.929
Cleveland, OH	14820	0.049	0.214	0.479	1.251	2.897	6.712	12.611	0.018	0.064	0.128	0.353	1.038	3.634	9.059
Denver, CO	23062	0.054	0.237	0.518	1.401	3.393	8.397	16.369	0.020	0.075	0.148	0.391	1.137	4.262	11.383
Fresno, CA	93193	0.077	0.344	0.744	1.858	4.018	9.168	17.785	0.028	0.101	0.205	0.562	1.556	5.002	12.248
Harrisburg, PA	14751	0.047	0.214	0.477	1.269	2.978	6.960	13.027	0.018	0.066	0.131	0.357	1.049	3.731	9.318
Hartford, CT	14740	0.049	0.212	0.474	1.283	2.999	7.096	14.060	0.018	0.067	0.132	0.354	1.050	3.762	9.585
Houston, TX	12960	0.042	0.191	0.424	1.129	2.696	6.640	12.839	0.016	0.059	0.119	0.320	0.933	3.392	8.910
Huntington, WV	3860	0.057	0.248	0.548	1.450	3.416	8.647	17.196	0.021	0.077	0.153	0.410	1.191	4.284	11.707
Las Vegas, NV	23169	0.045	0.194	0.432	1.185	2.852	6.949	13.504	0.017	0.062	0.122	0.323	0.961	3.588	9.440
Lincoln, NE	14939	0.032	0.142	0.317	0.867	2.046	4.850	9.212	0.012	0.045	0.088	0.237	0.708	2.566	6.520
Little Rock, AR	13963	0.045	0.201	0.442	1.181	2.830	7.049	13.894	0.017	0.063	0.126	0.335	0.967	3.553	9.533
Los Angeles, CA	24174	0.055	0.255	0.564	1.466	3.232	7.230	14.069	0.020	0.076	0.153	0.465	1.263	4.022	9.655
Miami, FL	12839	0.041	0.181	0.404	1.080	2.521	6.016	11.650	0.015	0.056	0.112	0.303	0.889	3.163	8.083
Minneapolis, MN	14922	0.033	0.147	0.326	0.896	2.168	5.320	10.290	0.013	0.047	0.093	0.246	0.729	2.726	7.166
Philadelphia, PA	13739	0.045	0.198	0.439	1.200	2.876	6.962	13.365	0.017	0.063	0.124	0.330	0.978	3.610	9.369
Phoenix, AZ	23183	0.062	0.274	0.597	1.555	3.628	8.793	16.962	0.023	0.085	0.170	0.455	1.281	4.533	11.828
Portland, ME	14764	0.046	0.196	0.433	1.209	3.056	7.866	15.636	0.018	0.065	0.126	0.327	0.972	3.857	10.701
Raleigh-Durham, NC	13722	0.043	0.191	0.424	1.152	2.802	6.956	13.566	0.016	0.061	0.120	0.320	0.936	3.523	9.394
Salem, OR	24232	0.048	0.209	0.466	1.287	3.060	7.288	13.859	0.018	0.067	0.130	0.347	1.045	3.844	9.833
Salt Lake City, UT	24127	0.052	0.232	0.514	1.386	3.218	7.569	14.453	0.020	0.072	0.142	0.383	1.131	4.041	10.268
San Francisco, CA	23234	0.046	0.207	0.464	1.252	2.975	7.163	13.747	0.018	0.065	0.127	0.345	1.029	3.743	9.704
Seattle, WA	24233	0.053	0.240	0.540	1.440	3.187	7.022	12.804	0.020	0.073	0.145	0.399	1.193	3.974	9.363
Winnemucca, NV	24128	0.040	0.172	0.380	1.040	2.555	6.432	12.676	0.015	0.056	0.109	0.287	0.842	3.211	8.724

Table B-8. Maximum Annual Average Unitized Air Concentrations ($\mu\text{g}/\text{m}^3/\mu\text{g}/\text{s}\cdot\text{m}^2$) for Aerated and Storage Tanks

n	Station	Area (m^2)	
	No.	27	430
Albuquerque, NM	23050	0.00286	0.04652
Atlanta, GA	13874	0.00333	0.06414
Bismarck, ND	24011	0.00245	0.04142
Boise, ID	24131	0.00519	0.09329
Casper, WY	24089	0.00425	0.08087
Charleston, SC	13880	0.00257	0.04466
Chicago, IL	94846	0.00248	0.04656
Cleveland, OH	14820	0.00408	0.07670
Denver, CO	23062	0.00383	0.06834
Fresno, CA	93193	0.00652	0.12357
Harrisburg, PA	14751	0.00378	0.06610
Hartford, CT	14740	0.00462	0.07620
Houston, TX	12960	0.00321	0.06281
Huntington, WV	3860	0.00403	0.07845
Las Vegas, NV	23169	0.00265	0.04930
Lincoln, NE	14939	0.00336	0.05724
Little Rock, AR	13963	0.00272	0.04850
Los Angeles, CA	24174	0.00779	0.12923
Miami, FL	12839	0.00328	0.05823
Minneapolis, MN	14922	0.00235	0.04401
Philadelphia, PA	13739	0.00350	0.05938
Phoenix, AZ	23183	0.00506	0.08872
Portland, ME	14764	0.00317	0.05184
Raleigh-Durham, NC	13722	0.00302	0.05285
Salem, OR	24232	0.00532	0.08962
Salt Lake City, UT	24127	0.00465	0.08360
San Francisco, CA	23234	0.00543	0.09108
Seattle, WA	24233	0.00594	0.10704
Winnemucca, NV	24128	0.00282	0.04978

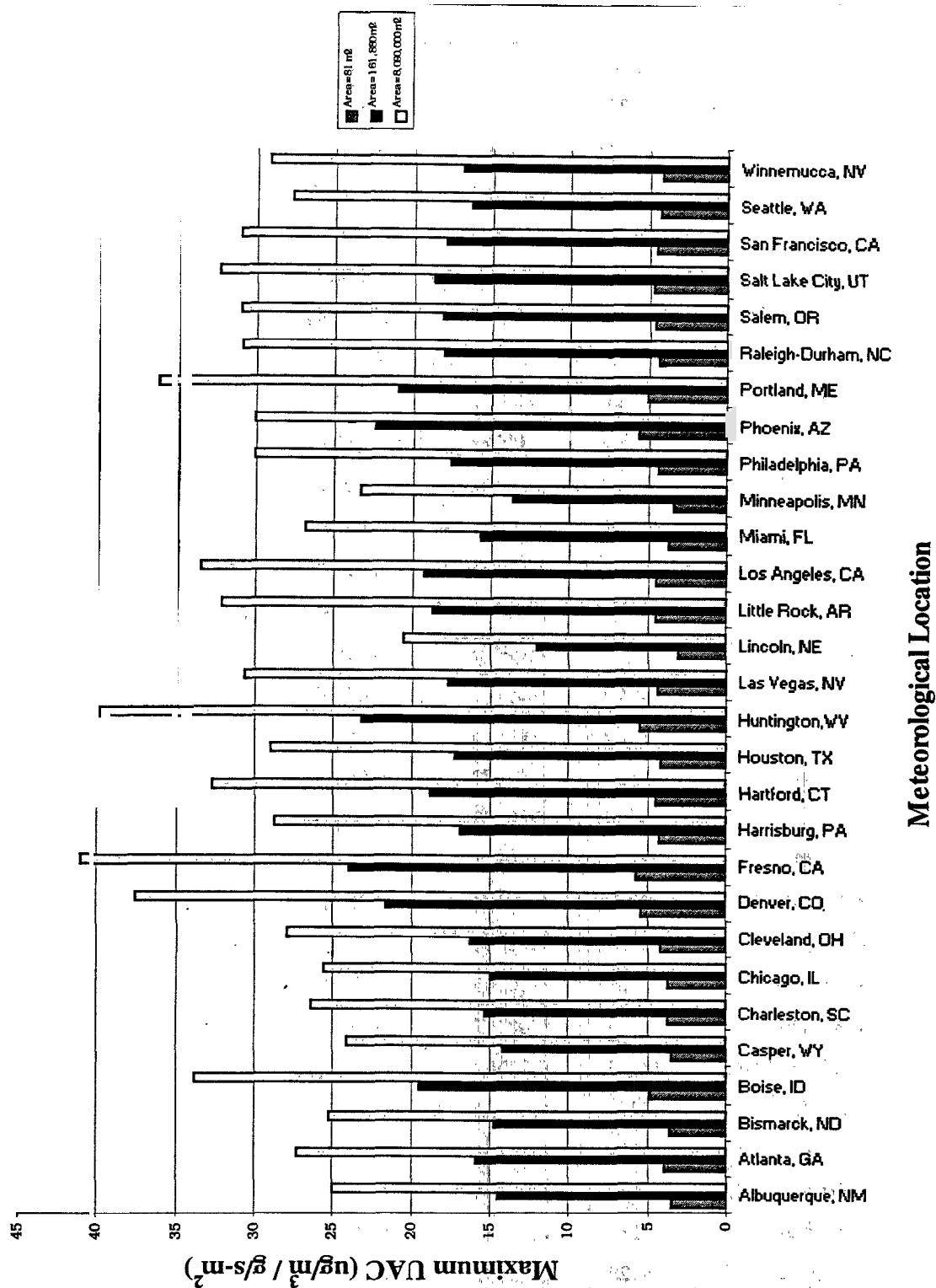


Figure B-3. Maximum UAC by meteorological location (landfills and LAUs).

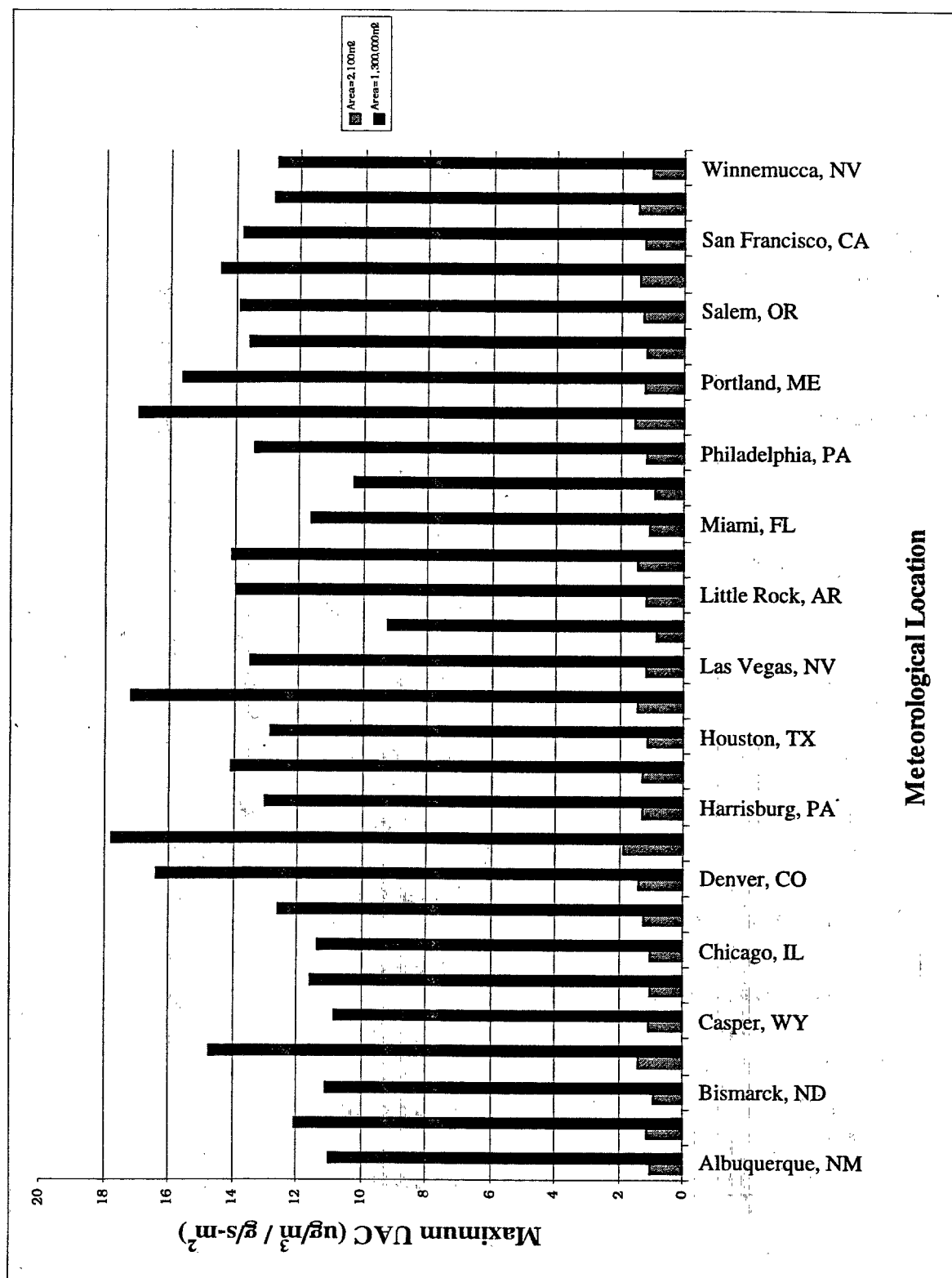


Figure B-4. Maximum UAC by meteorological location (2-m wastepiles).

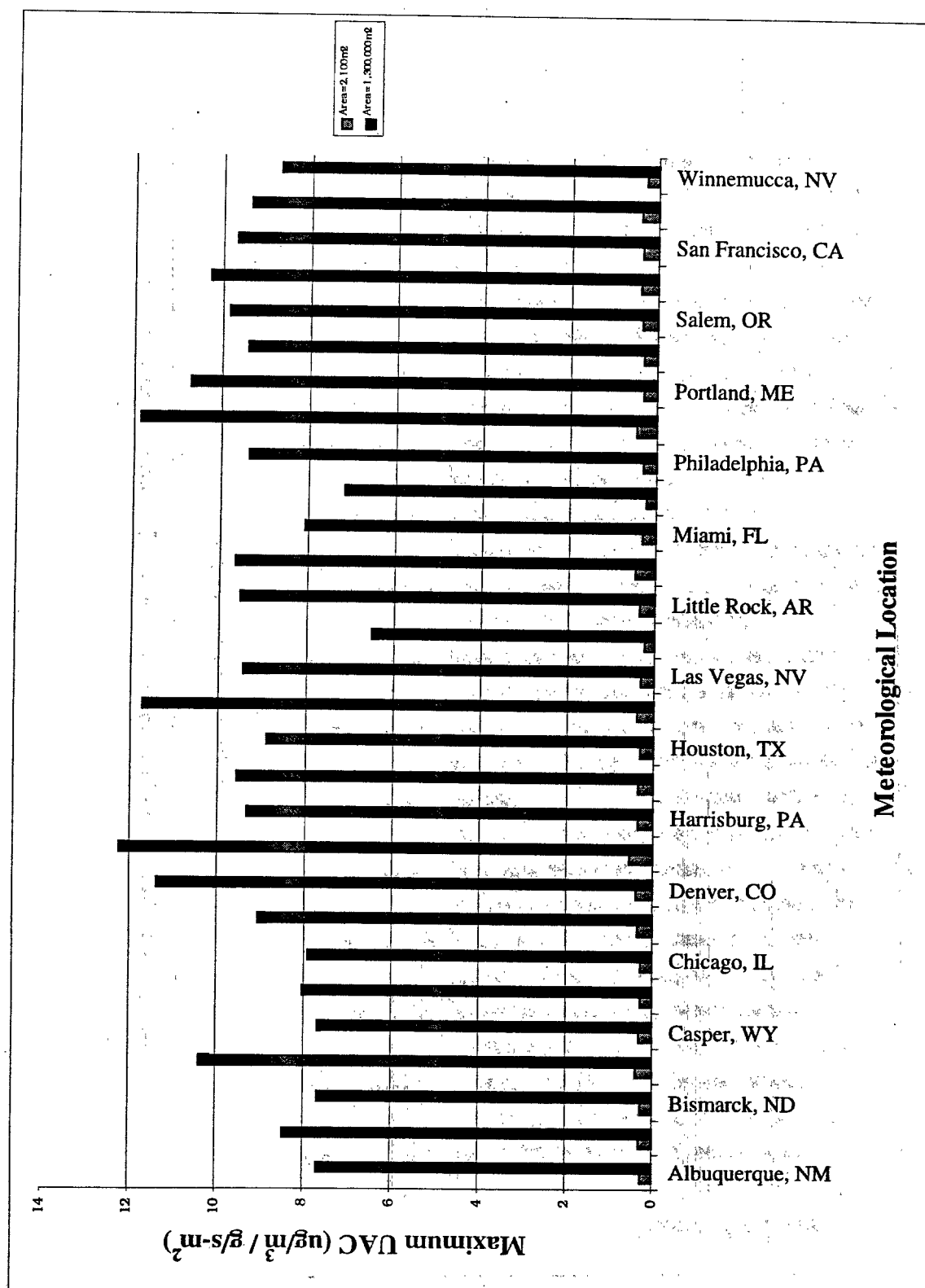


Figure B-5. Maximum UAC by meteorological location (5-m wastepiles).

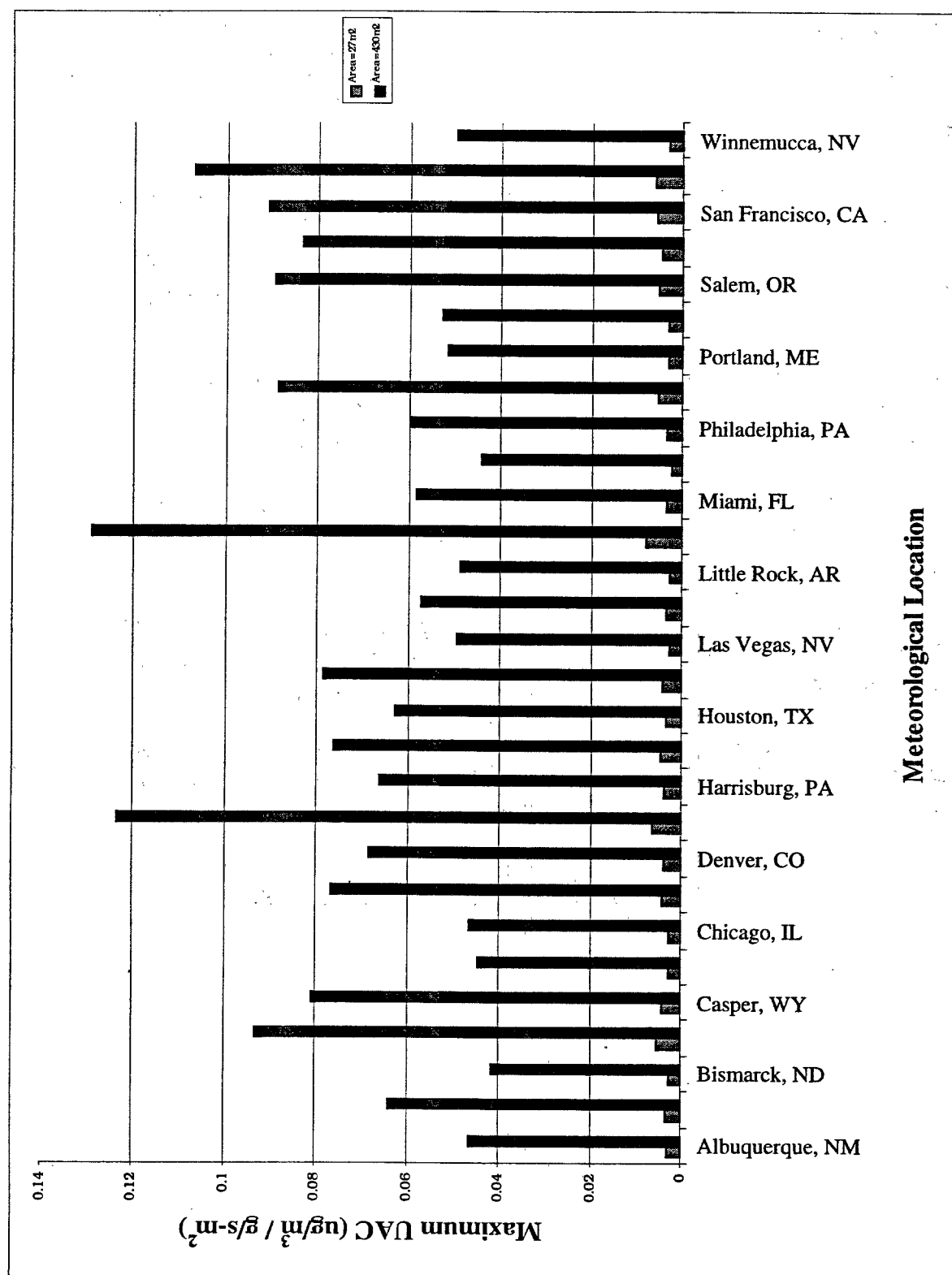


Figure B-6. Maximum UAC by meteorological location (tanks).

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Appendix C

Sensitivity Analysis of ISC Air Model

Appendix C

Sensitivity Analysis of ISC Air Model

This appendix describes sensitivity analysis on depletion options, source shape and orientation, and receptor location and spacing.

C.1 Options With and Without Depletions

A sensitivity analysis was conducted using the ISCST3 model to determine whether dry and wet depletion options should be used in the risk analysis for five types of waste management units. A discussion of the analysis follows.

The depletion options (dry depletion and wet depletion) may be used with concentrations and depositions in the ISCST3 model runs. The model concentrations/depositions without depletion are higher than those with depletion. Because it takes much longer to run the ISCST3 model with depletions than without depletions, a sensitivity analysis was performed to investigate the differences of model outputs with and without selecting depletion options.

In this investigation, the 5th and the 95th percentile of sizes of LAUs were used to determine the relationship between concentrations with depletions and sizes of units.

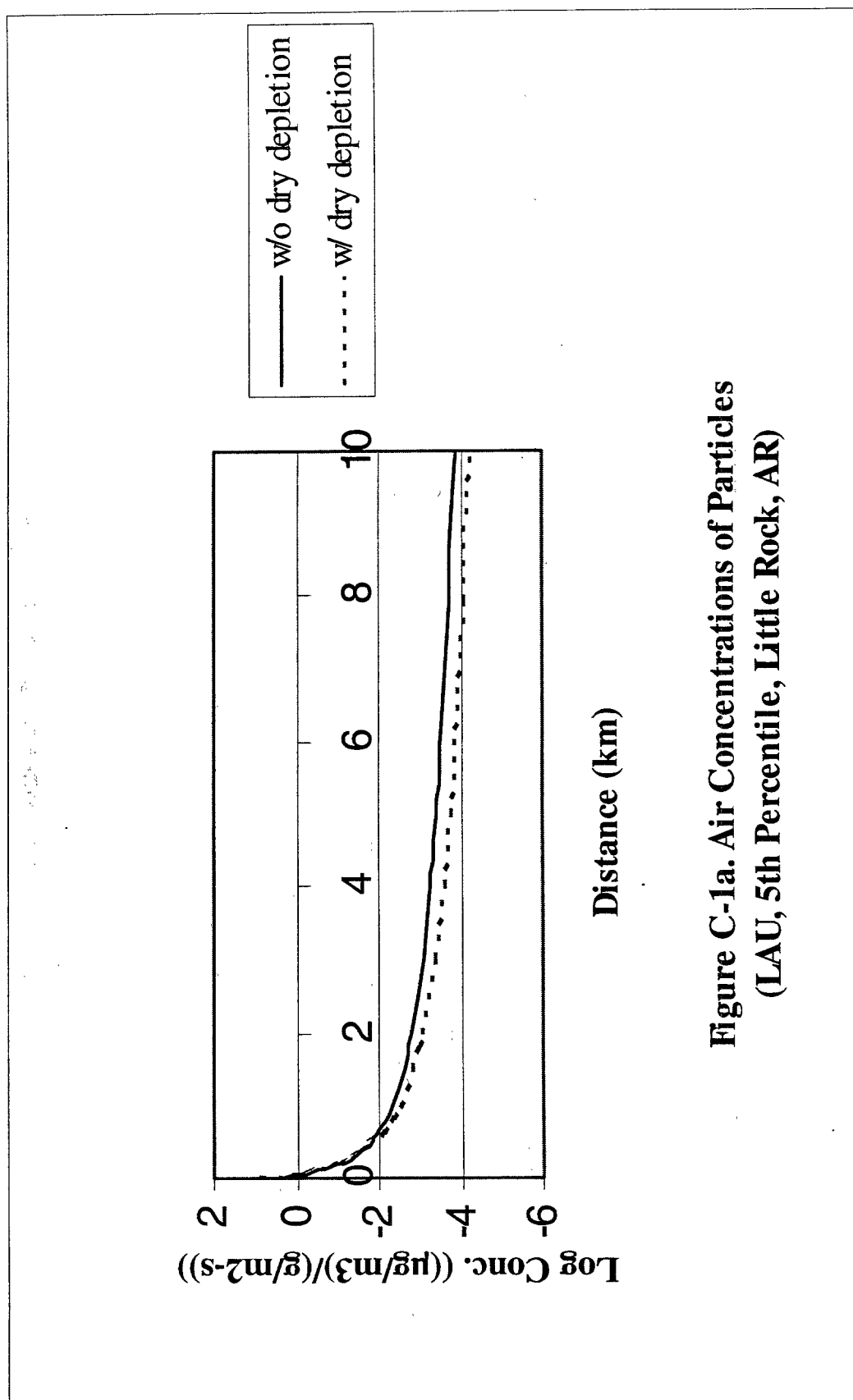
For dry depletion, two meteorological stations (Little Rock, Arkansas, and Winnemucca, Nevada) were selected for the sensitivity analysis. The average particle sizes used in the sensitivity analysis are 20 μm and 5 μm with corresponding mass fraction of 50 percent each. The roughness length at application site was assumed as 0.4 meters.

For wet depletion, two meteorological stations were selected for the sensitivity analysis: Atlanta, Georgia, with 49.8 inches precipitation per year (4th highest annual precipitation rate among the 29 meteorological stations to be modeled), and Winnemucca, Nevada, with 8.1 inches precipitation per year (3rd lowest annual precipitation rate). The reason for selecting a wet site and a dry site was to examine (1) whether wet depletion has a more significant impact for a wet site than a dry site; and (2) the differences of ambient concentrations that a very wet site can make with and without selecting wet depletion.

Five-year average concentrations with and without dry depletion were calculated using meteorological data from Little Rock and Winnemucca for the 5th and the 95th percentile of sizes of LAUs. The results show that the differences of the maximum concentrations with and without dry depletion are very small at close-to-source receptors. As the distance from the source increases, the differences between the dry depletion option and without dry depletion increase only slightly. The differences of concentrations are about 10 percent of the concentrations for the

95th percentile and are less than 2 percent of the concentrations for the 5th percentile at 50 meters from the edge of the LAU. The larger the area source, the larger the differences of the maximum concentrations. The results are shown in Figures C-1a through C-1d.

Five-year average concentrations with and without wet depletion also were calculated using meteorological data from Atlanta and Winnemucca for the 5th and 95th percentile of sizes of LAUs. The results show that the differences of the maximum concentrations with and without wet depletion are small for both Atlanta and Winnemucca sites. However, the differences in the maximum concentrations between the wet depletion option and without wet depletion are about 5 to 10 times greater for the Atlanta site than the Winnemucca site. Tables C-1a and C-1b show that for the 95th percentile unit size, at 50 meters from the edge of the unit, the differences in the maximum concentrations are only 0.03% and 0.37% for Winnemucca and Atlanta, respectively. This means that model concentrations with and without wet depletion are about the same.



**Figure C-1a. Air Concentrations of Particles
(LAU, 5th Percentile, Little Rock, AR)**

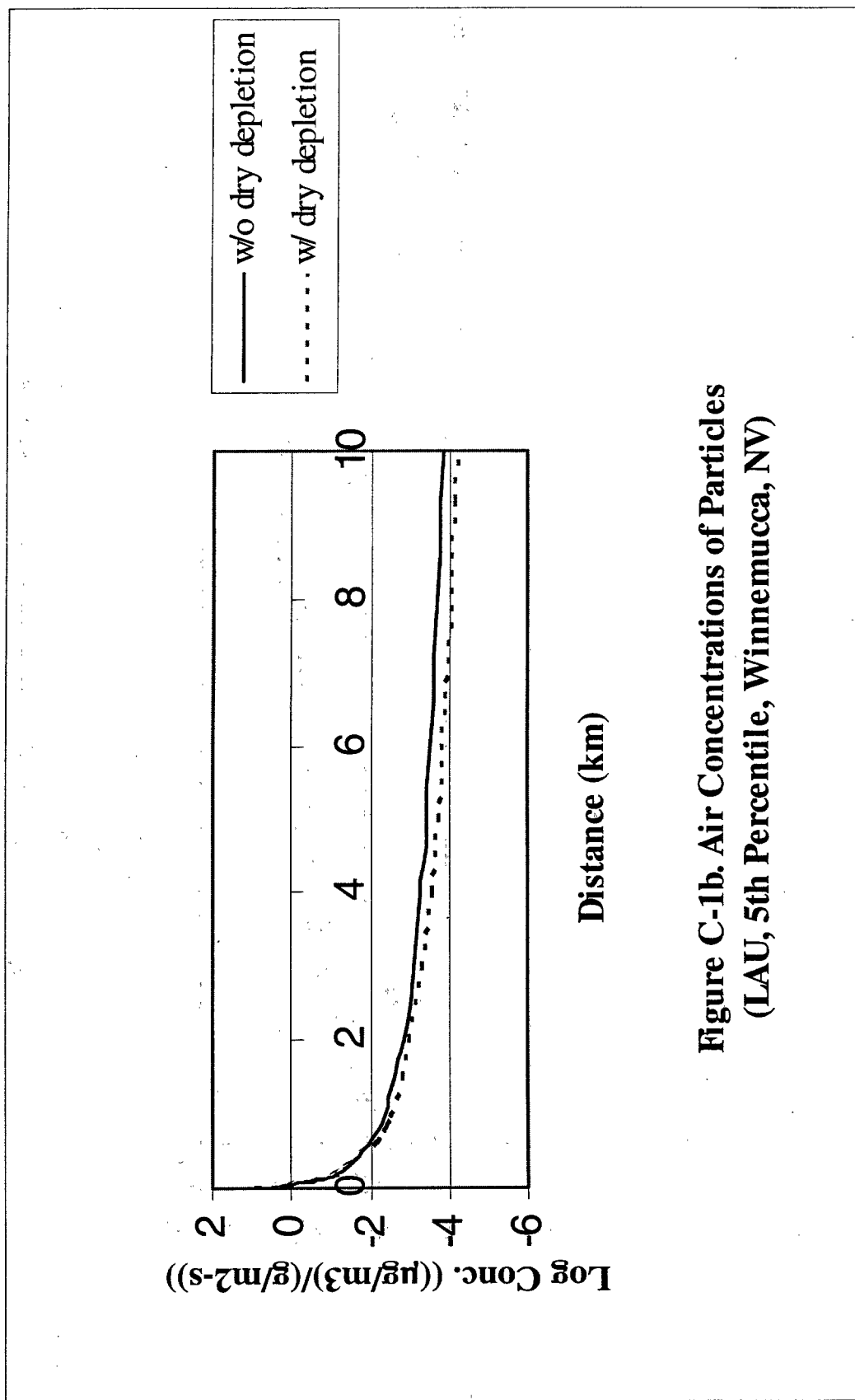
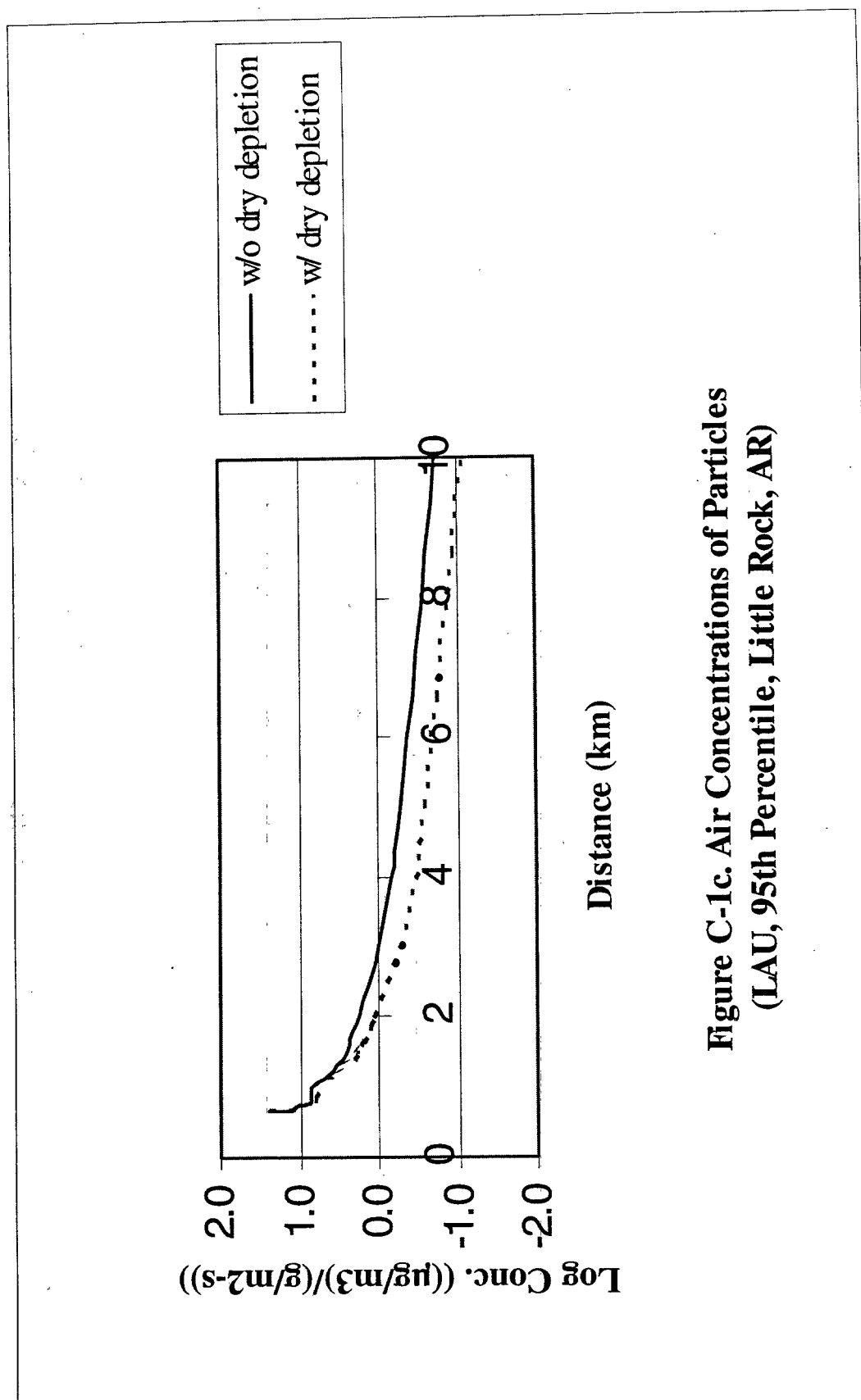
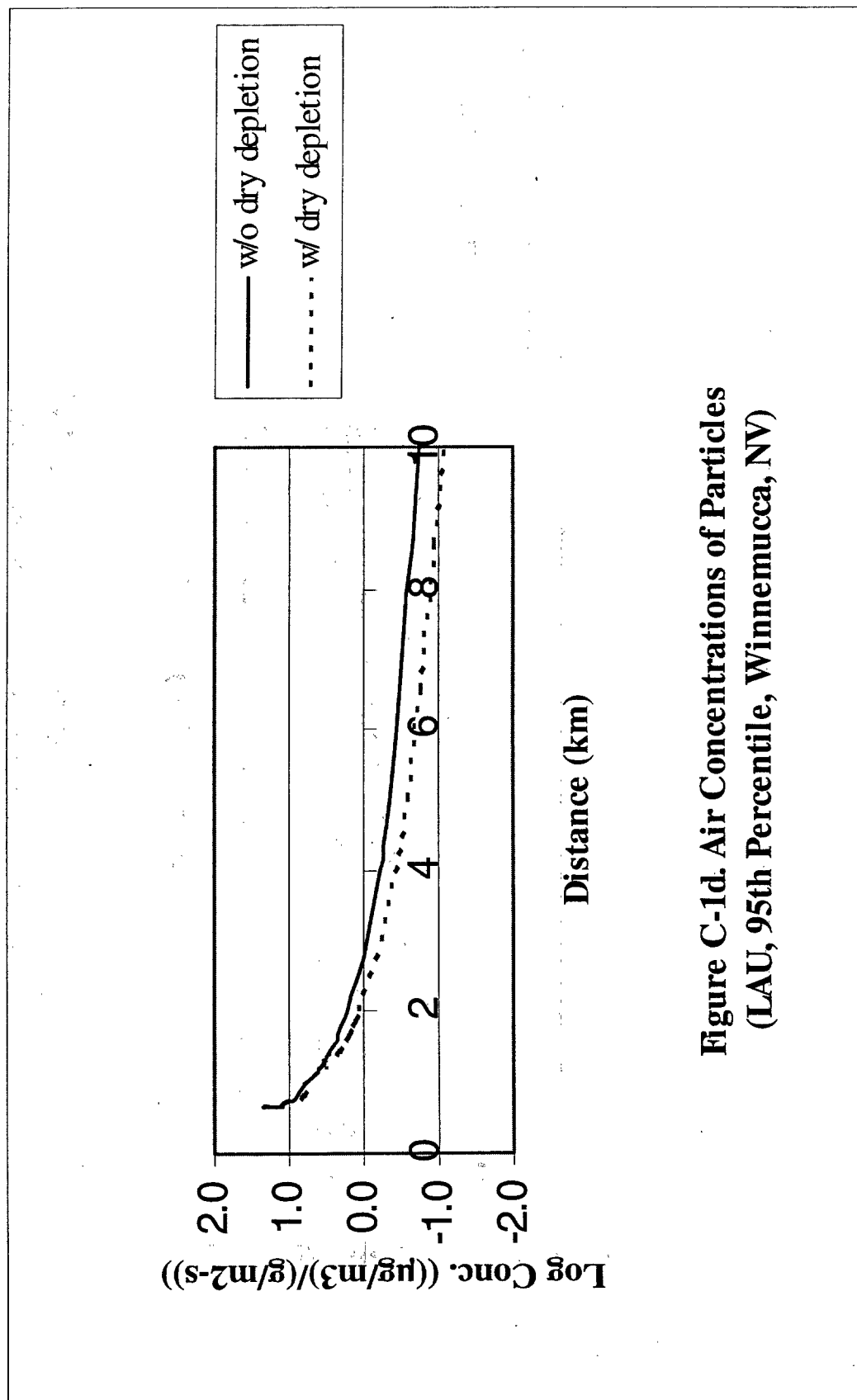


Figure C-1b. Air Concentrations of Particles
(LAU, 5th Percentile, Winnemucca, NV)



**Figure C-1c. Air Concentrations of Particles
(LAU, 95th Percentile, Little Rock, AR)**



**Figure C-1d. Air Concentrations of Particles
(LAU, 95th Percentile, Winnemucca, NV)**

Table C-1a. Differences of Air Concentrations for Vapors Between Wet Depletion Option and Without Wet Depletion

(Atlanta, GA Site)																			
5th Percentile				95th Percentile															
w/o wet depletion		w/ wet depletion		w/o wet depletion		w/ wet depletion													
Distance	Concentrations	Concentrations	Difference	Distance	Concentrations	Concentrations	Difference	Distance	Concentrations	Concentrations	Difference	Distance	Concentrations	Concentrations	Difference	Distance	Concentrations	Difference	Percentage
(m)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(m)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(m)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(m)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	(m)	(ug/m ³ /g/m ² -s)	(ug/m ³ /g/m ² -s)	Percentage
19.3 ⁽¹⁾	7.40752	7.40716	0.00036	651.9 ⁽¹⁾	0.00614	0.00612	0.00002	651.9 ⁽¹⁾	0.00614	0.00612	0.00002	651.9 ⁽¹⁾	0.00614	0.00612	0.00002	651.9 ⁽¹⁾	0.00614	0.00612	0.33%
47.3 ⁽¹⁾	0.93175	0.93159	0.00016	676.9 ⁽¹⁾	0.00574	0.00573	0.00001	676.9 ⁽¹⁾	0.00574	0.00573	0.00001	676.9 ⁽¹⁾	0.00574	0.00573	0.00001	676.9 ⁽¹⁾	0.00574	0.00573	0.17%
75.2 ⁽¹⁾	0.38178	0.38168	0.00010	701.9 ⁽¹⁾	0.00539	0.00537	0.00002	701.9 ⁽¹⁾	0.00539	0.00537	0.00002	701.9 ⁽¹⁾	0.00539	0.00537	0.00002	701.9 ⁽¹⁾	0.00539	0.00537	0.37%
100	0.25129	0.25121	0.00008	726.9 ⁽¹⁾	0.00507	0.00505	0.00002	726.9 ⁽¹⁾	0.00507	0.00505	0.00002	726.9 ⁽¹⁾	0.00507	0.00505	0.00002	726.9 ⁽¹⁾	0.00507	0.00505	0.39%
103.2 ⁽¹⁾	0.21003	0.20996	0.00007	801.9 ⁽¹⁾	0.00427	0.00426	0.00001	801.9 ⁽¹⁾	0.00427	0.00426	0.00001	801.9 ⁽¹⁾	0.00427	0.00426	0.00001	801.9 ⁽¹⁾	0.00427	0.00426	0.23%
187.0 ⁽¹⁾	0.06886	0.06882	0.00004	1000	0.00400	0.00399	0.00001	1000	0.00400	0.00399	0.00001	1000	0.00400	0.00399	0.00001	1000	0.00400	0.00399	0.25%
200	0.07091	0.07086	0.00005	1100	0.00342	0.00341	0.00001	1100	0.00342	0.00341	0.00001	1100	0.00342	0.00341	0.00001	1100	0.00342	0.00341	0.29%
300	0.03390	0.03387	0.00003	1200	0.00296	0.00295	0.00001	1200	0.00296	0.00295	0.00001	1200	0.00296	0.00295	0.00001	1200	0.00296	0.00295	0.34%
400	0.02026	0.02024	0.00002	1300	0.00260	0.00259	0.00001	1300	0.00260	0.00259	0.00001	1300	0.00260	0.00259	0.00001	1300	0.00260	0.00259	0.38%
500	0.01359	0.01357	0.00002	1400	0.00230	0.00229	0.00001	1400	0.00230	0.00229	0.00001	1400	0.00230	0.00229	0.00001	1400	0.00230	0.00229	0.43%
600	0.00981	0.00979	0.00002	1500	0.00205	0.00205	0.00000	1500	0.00205	0.00205	0.00000	1500	0.00205	0.00205	0.00000	1500	0.00205	0.00205	0.00%
800	0.00590	0.00589	0.00001	1600	0.00185	0.00184	0.00001	1600	0.00185	0.00184	0.00001	1600	0.00185	0.00184	0.00001	1600	0.00185	0.00184	0.54%
1000	0.00400	0.00399	0.00001	1800	0.00152	0.00152	0.00000	1800	0.00152	0.00152	0.00000	1800	0.00152	0.00152	0.00000	1800	0.00152	0.00152	0.00%
1500	0.00205	0.00205	0.00000	2000	0.00128	0.00128	0.00000	2000	0.00128	0.00128	0.00000	2000	0.00128	0.00128	0.00000	2000	0.00128	0.00128	0.00%
2000	0.00128	0.00128	0.00000	3000	0.00068	0.00067	0.00001	3000	0.00068	0.00067	0.00001	3000	0.00068	0.00067	0.00001	3000	0.00068	0.00067	1.47%
3000	0.00068	0.00067	0.00001	4000	0.00044	0.00043	0.00001	4000	0.00044	0.00043	0.00001	4000	0.00044	0.00043	0.00001	4000	0.00044	0.00043	2.27%
4000	0.00044	0.00043	0.00001	5000	0.00031	0.00031	0.00000	5000	0.00031	0.00031	0.00000	5000	0.00031	0.00031	0.00000	5000	0.00031	0.00031	0.00%
5000	0.00031	0.00031	0.00000	10000	0.00011	0.00011	0.00000	10000	0.00011	0.00011	0.00000	10000	0.00011	0.00011	0.00000	10000	0.00011	0.00011	0.00%
10000	0.00011	0.00011	0.00000																

(1) These refer to the distances from the center of emission source to the maximum concentration points along 0, 25, 50, 75, and 150 meter receptor squares, respectively.

C-8

C-8

C-8

C.2 Source Shape and Orientation

A sensitivity analysis was conducted using the ISCST3 air model to determine what role source shape and orientation play in determining dispersion coefficients of air pollutants. A discussion of this analysis follows.

Three different sources were chosen for this analysis. The sources were a square (source No. 1), a rectangle oriented east to west (source No. 2), and a rectangle oriented north to south (source No. 3). All three sources had an area of 400 m^2 in order to ensure that equal emission rates were compared. The rectangles were selected to be exactly two times longer and half as wide as the square (see Figure C-2).

Two meteorological stations at Little Rock, Arkansas, and Los Angeles, California, were selected for this modeling analysis in order to compare two different meteorological regimes. Little Rock was selected because of its evenly distributed wind directions and Los Angeles was selected because it has a predominantly southwest wind direction (see Figure C-3). Five years of meteorological data were used for this analysis.

Each area source was modeled with similar receptor grids to ensure consistency. Sixteen receptors were placed on the edge of each of the area sources and another 16 were placed 25 meters out from the edge. Each of these two receptor groups were modeled as a Cartesian receptor grid. Two receptor rings were also placed at 50 and 100 meters out from the center of the source. This polar receptor grid consisted of 16 receptors with a 22.5 degree interval between receptors. See Figures C-4a through C-4c for receptor locations.

The ISCST3 model was run using the meteorological data from Little Rock, Arkansas, and Los Angeles, California, and the results are shown in Tables C-2a and C-2b. The results indicated that the standard deviation of the differences in air concentrations is greatest between source No. 2 and source No. 3. This difference is due to the orientation of the source. This occurs for both the Cartesian receptor grid and the polar receptor grid at both meteorological locations. This shows that the model is sensitive to the orientation of the rectangular area source.

Standard deviations are significantly smaller when source No. 1 is compared to source Nos. 2 or 3. This shows that the differences in Unitized Air Concentration (UAC) between the square source and the two rectangular sources are less than the differences between the two rectangular sources. A square area source also contributes the least amount of impact of orientation. Since no information on source shape or orientation is available, a square source will minimize the errors caused by different source shapes and orientations.

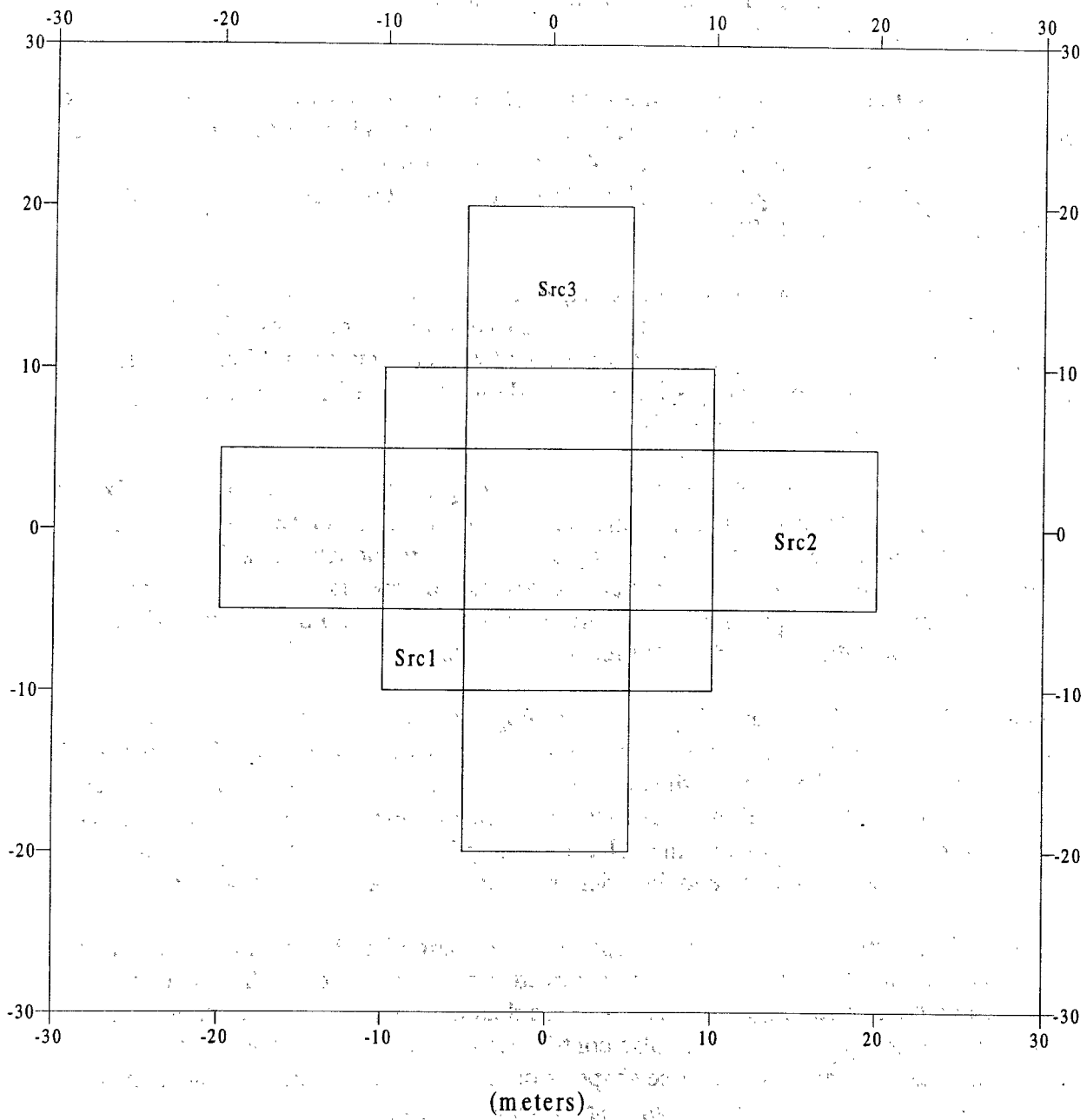
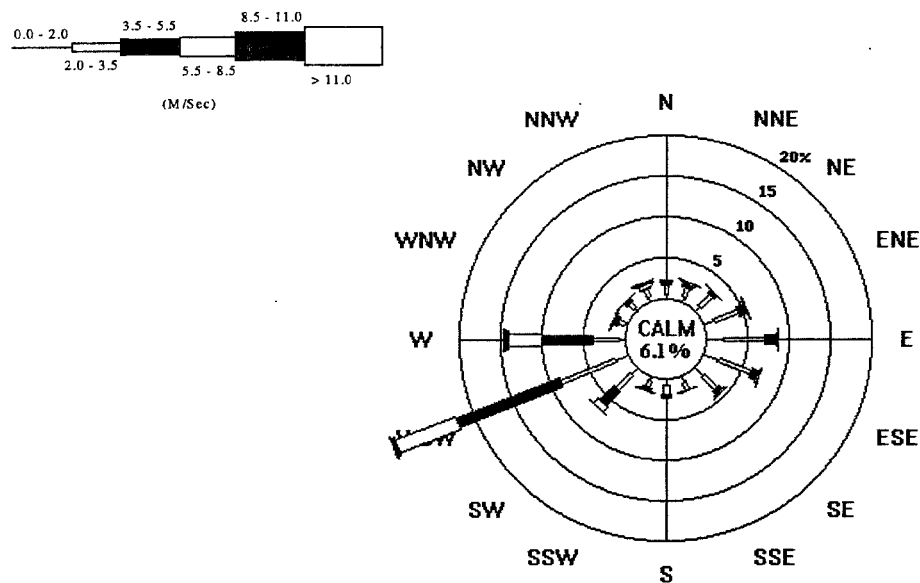


Figure C-2. Source Shapes and Orientations

Los Angeles, California



Little Rock, Arkansas

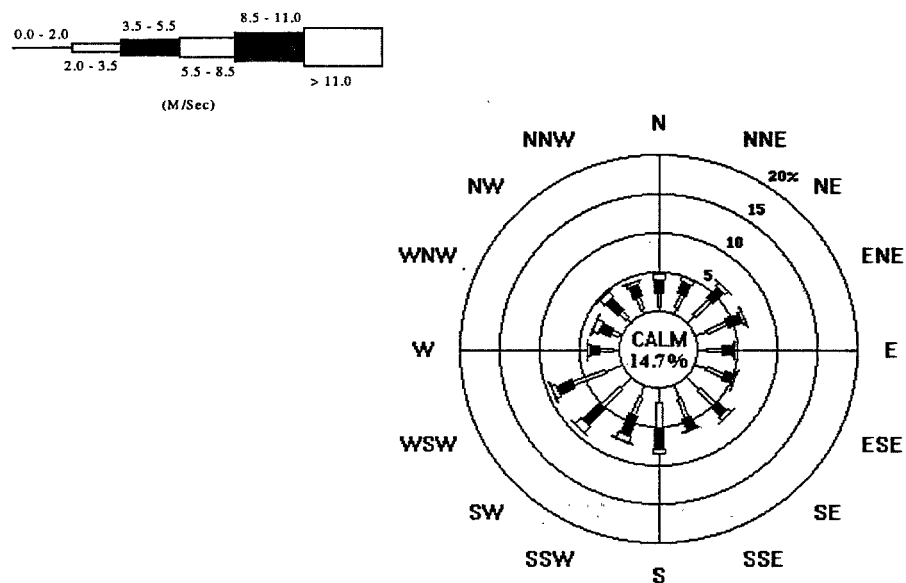


Figure C-3. Wind Roses

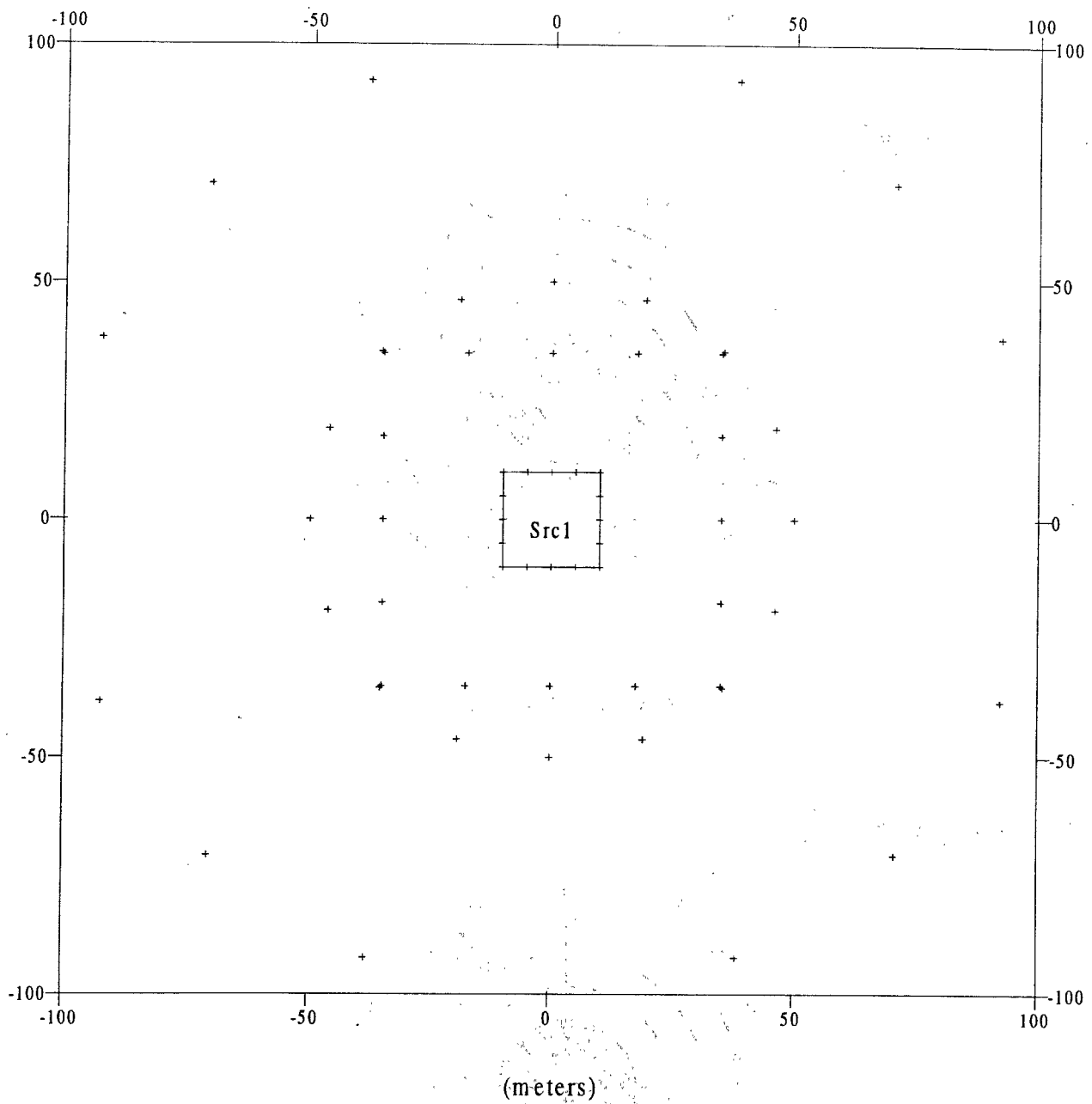
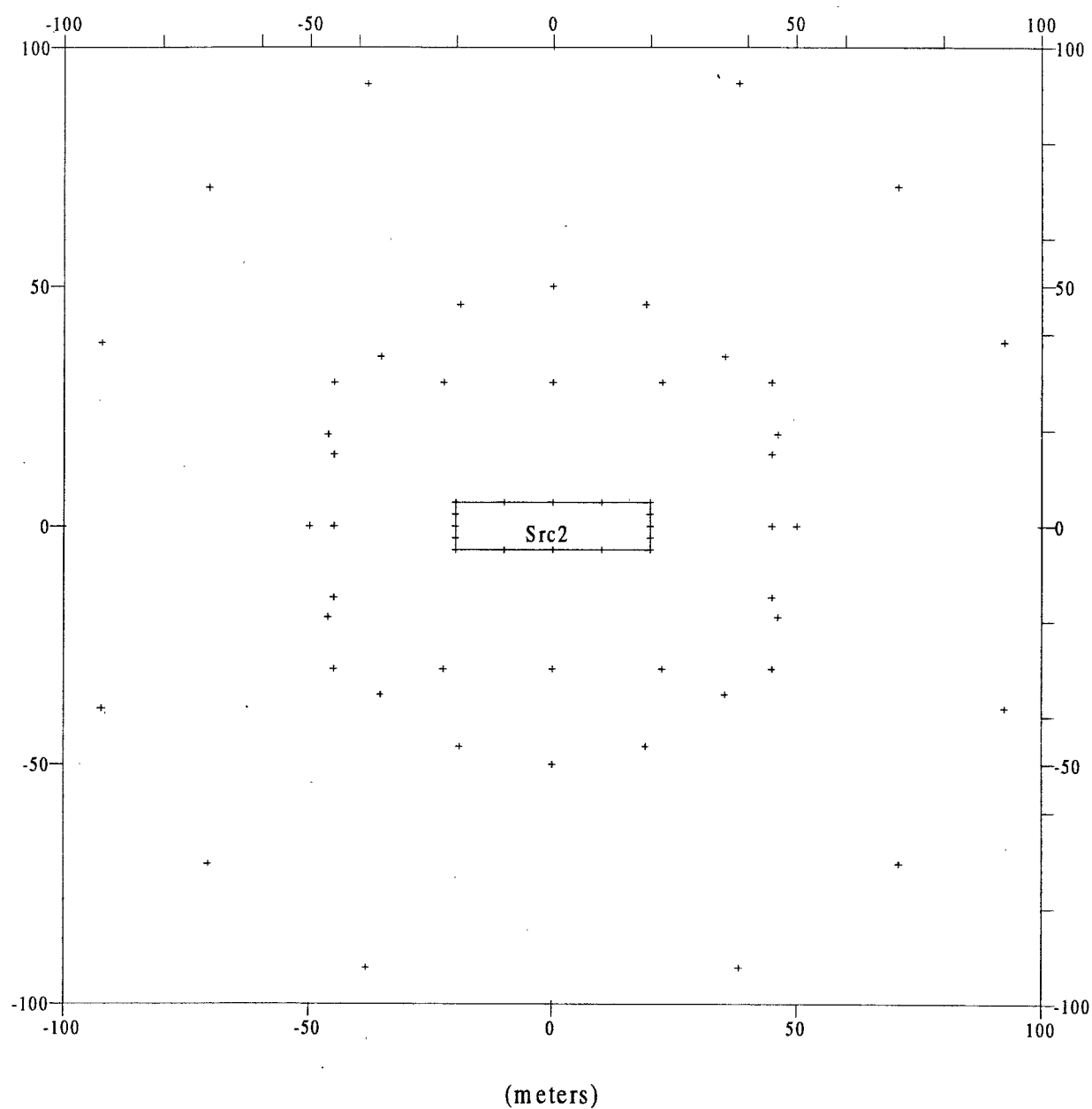


Figure C-4a. Receptor Locations (Source No. 1)

**Figure C-4b. Receptor Locations (Source No. 2)**

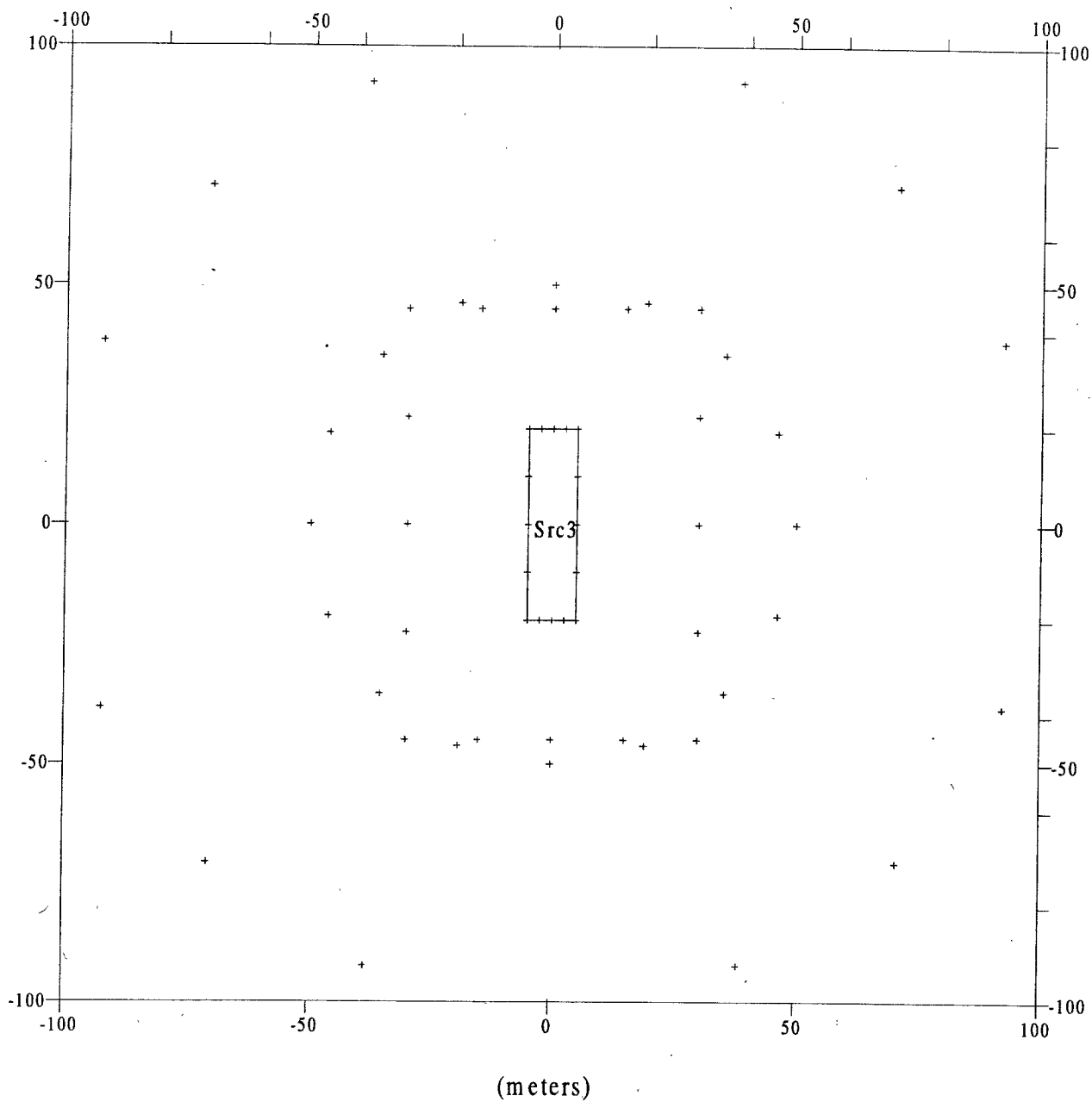


Figure C-4c. Receptor Locations (Source No. 3)

Table C-2a. Comparison of Unitized Air Concentration ($\mu\text{g}/\text{m}^3/\mu\text{g}/\text{s}\cdot\text{m}^2$) for Different Source Shapes and Orientations

(Little Rock, Arkansas)																	
Source No. 1 (20m x 20m)				Source No. 2 (40m x 10m)				Source No. 3 (10m x 40m)				Differences in UACs		Differences in UACs		Differences in UACs	
Polar Receptor Grid												Sources No. 1 and No. 2		Sources No. 1 and No. 3		Sources No. 2 and No. 3	
X(m)	Y(m)	UAC		X(m)	Y(m)	UAC		X(m)	Y(m)	UAC		Diff. In UAC	% of Diff.	Diff. In UAC	% of Diff.	Diff. In UAC	% of Diff.
19	46	0.190		19	46	0.199		19	46	0.211		0.010	5%	0.021	11%	0.012	6%
38	92	0.050		38	92	0.051		38	92	0.051		0.001	1%	0.001	2%	0.000	1%
35	35	0.249		35	35	0.243		35	35	0.278		-0.007	-3%	0.028	11%	0.035	14%
71	71	0.067		71	71	0.067		71	71	0.069		-0.001	-1%	0.001	2%	0.002	3%
46	19	0.321		46	19	0.361		46	19	0.256		0.041	13%	-0.065	-20%	-0.105	-29%
92	38	0.095		92	38	0.098		92	38	0.088		0.003	3%	-0.007	-7%	-0.010	-10%
50	0	0.124		50	0	0.128		50	0	0.147		0.004	3%	0.023	19%	0.020	15%
100	0	0.030		100	0	0.030		100	0	0.033		0.000	-1%	0.003	9%	0.003	11%
46	-19	0.085		46	-19	0.096		46	-19	0.084		0.011	12%	-0.001	-1%	-0.011	-12%
92	-38	0.023		92	-38	0.024		92	-38	0.023		0.001	2%	-0.001	-2%	-0.001	-5%
35	-35	0.106		35	-35	0.109		35	-35	0.103		0.003	3%	-0.003	-3%	-0.006	-6%
71	-71	0.030		71	-71	0.030		71	-71	0.029		0.000	0%	0.000	-1%	-0.001	-2%
19	-46	0.117		19	-46	0.113		19	-46	0.128		-0.005	-4%	0.011	9%	0.016	14%
38	-92	0.033		38	-92	0.032		38	-92	0.034		-0.001	-4%	0.001	2%	0.002	7%
0	-50	0.122		0	-50	0.117		0	-50	0.143		-0.005	-4%	0.021	17%	0.026	22%
0	-100	0.035		0	-100	0.033		0	-100	0.037		-0.002	-5%	0.002	5%	0.004	11%
-19	-46	0.134		-19	-46	0.128		-19	-46	0.150		-0.006	-4%	0.016	12%	0.022	17%
-38	-92	0.038		-38	-92	0.036		-38	-92	0.038		-0.002	-4%	0.001	2%	0.002	6%
-35	-35	0.161		-35	-35	0.158		-35	-35	0.170		-0.003	-2%	0.009	6%	0.012	8%
-71	-71	0.043		-71	-71	0.043		-71	-71	0.045		0.000	1%	0.001	3%	0.001	3%
-46	-19	0.159		-46	-19	0.185		-46	-19	0.140		0.026	16%	-0.019	-12%	-0.045	-24%
-92	-38	0.044		-92	-38	0.046		-92	-38	0.043		0.002	4%	-0.002	-4%	-0.004	-8%
-50	0	0.103		-50	0	0.114		-50	0	0.107		0.011	11%	0.004	4%	-0.007	-6%
-100	0	0.027		-100	0	0.027		-100	0	0.027		0.000	2%	0.000	1%	0.000	0%
-46	19	0.126		-46	19	0.145		-46	19	0.118		0.019	15%	-0.008	-6%	-0.027	-18%
-92	38	0.035		-92	38	0.036		-92	38	0.034		0.001	4%	-0.001	-4%	-0.003	-7%
-35	35	0.152		-35	35	0.160		-35	35	0.153		0.008	5%	0.001	0%	-0.007	-5%
-71	71	0.041		-71	71	0.042		-71	71	0.041		0.001	3%	0.001	2%	-0.001	-2%
-19	46	0.173		-19	46	0.179		-19	46	0.187		0.007	4%	0.014	8%	0.008	4%
-38	92	0.047		-38	92	0.047		-38	92	0.048		0.000	0%	0.001	3%	0.001	3%
0	50	0.224		0	50	0.191		0	50	0.276		-0.032	-14%	0.052	23%	0.085	44%
0	100	0.068		0	100	0.061		0	100	0.074		-0.008	-11%	0.006	9%	0.014	22%
											Standard Deviation:	0.012	7%	0.018	9%	0.028	14%

(continued)

Table C-2a (continued).

Source No. 1 (20m x 20m)				Source No. 2 (40m x 10m)				Source No. 3 (10m x 40m)				(Little Rock, Arkansas)			
Cartesian Receptor Grid															
X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		Diff. In UAC	% of Diff.	Diff. In UAC	% of Diff.
-10	-10	3.014	-20	-5	2.675	-5	-20	2.673				-0.339	-11%	-0.341	-11%
-5	-10	4.266	-10	-5	4.219	-2.5	-20	3.451				-0.047	-1%	-0.815	-19%
0	-10	4.354	0	-5	4.307	0	-20	3.526				-0.047	-1%	-0.827	-19%
5	-10	3.961	10	-5	4.069	2.5	-20	3.152				0.109	3%	-0.809	-20%
10	-10	2.175	20	-5	1.899	5	-20	2.011				-0.276	-13%	-0.164	-8%
10	-5	5.211	20	-2.5	3.875	5	-10	5.567				-1.337	-26%	0.355	7%
10	0	5.968	20	0	4.704	5	0	5.913				-1.264	-21%	-0.055	-1%
10	5	6.012	20	2.5	4.918	5	10	5.834				-1.094	-18%	-0.178	-3%
10	10	4.946	20	5	4.468	5	20	4.344				-0.477	-10%	-0.602	-12%
5	10	6.804	10	5	6.758	2.5	20	5.550				-0.047	-1%	-1.254	-18%
0	10	6.846	0	5	6.830	0	20	5.604				-0.016	0%	-1.242	-18%
-5	10	6.157	-10	5	6.353	-2.5	20	4.954				0.196	3%	-1.203	-20%
-10	10	3.245	-20	5	2.793	-5	20	3.052				-0.451	-14%	-0.193	-6%
-10	5	4.923	-20	2.5	3.801	-5	10	5.166				-1.121	-23%	0.244	5%
-10	0	5.169	-20	0	4.032	-5	0	5.287				-1.137	-22%	0.118	2%
-10	-5	4.809	-20	-2.5	3.727	-5	-10	4.991				-1.081	-22%	0.182	4%
-35	-35	0.164	-45	-30	0.158	-30	-45	0.132				-0.006	-4%	-0.032	-19%
-17.5	-35	0.219	-22.5	-30	0.247	-15	-45	0.167				0.027	12%	-0.052	-24%
0	-35	0.243	0	-30	0.284	0	-45	0.179				0.041	17%	-0.063	-26%
35	-35	0.186	22.5	-30	0.192	15	-45	0.147				0.006	3%	-0.039	-21%
35	-35	0.108	45	-30	0.088	30	-45	0.100				-0.020	-19%	-0.008	-7%
35	-17.5	0.141	45	-15	0.105	30	-22.5	0.160				-0.036	-25%	0.019	14%
35	0	0.277	45	0	0.164	30	0	0.401				-0.113	-41%	0.124	45%
35	17.5	0.503	45	15	0.396	30	22.5	0.466				-0.107	-21%	-0.037	-7%
35	35	0.254	45	30	0.263	30	45	0.200				0.009	3%	-0.054	-21%
17.5	35	0.315	22.5	30	0.373	15	45	0.234				0.058	18%	-0.081	-26%
0	35	0.417	0	30	0.445	0	45	0.341				0.028	7%	-0.076	-18%
-17.5	35	0.272	-22.5	30	0.286	-15	45	0.214				0.014	5%	-0.057	-21%
-35	35	0.155	-45	30	0.131	-30	45	0.146				-0.024	-15%	-0.009	-6%
-35	17.5	0.211	-45	15	0.155	-30	22.5	0.232				-0.056	-27%	0.022	10%
-35	0	0.213	-45	0	0.145	-30	0	0.298				-0.068	-32%	0.084	40%
-35	-17.5	0.265	-45	-15	0.193	-30	-22.5	0.264				-0.073	-27%	-0.002	-1%
Standard Deviation:												0.463	15%	0.435	17%
												0.747	41%	0.747	41%

Table C-2b. Comparisons of Unitized Air Concentrations ($\mu\text{g}/\text{m}^3/\mu\text{g}/\text{s}\cdot\text{m}^3$) for Different Source Shapes and Orientations

(Los Angeles, California)												
Source No. 1 (20m x 20m)				Source No. 2 (40m x 10m)				Source No. 3 (10m x 40m)				
Polar Receptor Grid												
X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		
19	46	0.059		19	46	0.065		19	46	0.069		
38	92	0.016		38	92	0.016		38	92	0.016		
35	35	0.188		35	35	0.168		35	35	0.284		
71	71	0.046		71	71	0.045		71	71	0.052		
46	19	0.582		46	19	0.607		46	19	0.461		
92	38	0.172		92	38	0.174		92	38	0.161		
50	0	0.278		50	0	0.293		50	0	0.293		
100	0	0.068		100	0	0.067		100	0	0.074		
46	-19	0.061		46	-19	0.062		46	-19	0.087		
92	-38	0.015		92	-38	0.015		92	-38	0.016		
35	-35	0.062		35	-35	0.068		35	-35	0.062		
71	-71	0.016		71	-71	0.017		71	-71	0.017		
19	-46	0.080		19	-46	0.076		19	-46	0.087		
38	-92	0.023		38	-92	0.022		38	-92	0.024		
0	-50	0.086		0	-50	0.084		0	-50	0.096		
0	-100	0.023		0	-100	0.024		0	-100	0.024		
-19	-46	0.099		-19	-46	0.092		-19	-46	0.108		
-38	-92	0.028		-38	-92	0.027		-38	-92	0.028		
-35	-35	0.122		-35	-35	0.119		-35	-35	0.143		
-71	-71	0.033		-71	-71	0.032		-71	-71	0.034		
-46	-19	0.218		-46	-19	0.223		-46	-19	0.226		
-92	-38	0.060		-92	-38	0.061		-92	-38	0.061		
-50	0	0.320		-50	0	0.378		-50	0	0.278		
-100	0	0.093		-100	0	0.098		-100	0	0.087		
-46	19	0.264		-46	19	0.273		-46	19	0.260		
-92	38	0.074		-92	38	0.075		-92	38	0.073		
-35	35	0.137		-35	35	0.123		-35	35	0.164		
-71	71	0.037		-71	71	0.035		-71	71	0.039		
-19	46	0.063		-19	46	0.066		-19	46	0.073		
-38	92	0.017		-38	92	0.017		-38	92	0.018		
0	50	0.067		0	50	0.058		0	50	0.080		
0	100	0.020		0	100	0.018		0	100	0.021		

Differences in UACs Sources No. 1 and No. 2				Differences in UACs Sources No. 1 and No. 3				Differences in UACs Sources No. 2 and No. 3			
Diff. In UAC	% of Diff.			Diff. In UAC	% of Diff.			Diff. In UAC	% of Diff.		
0.006	9%			0.010	17%			0.005	7%		
0.000	-1%			0.000	3%			0.001	4%		
-0.020	-11%			0.096	51%			0.116	69%		
-0.001	-3%			0.006	13%			0.007	16%		
0.025	4%			-0.121	-21%			-0.146	-24%		
0.003	2%			-0.011	-6%			-0.014	-8%		
0.014	5%			0.015	5%			0.001	0%		
-0.001	-2%			0.005	8%			0.007	10%		
0.002	3%			0.026	43%			0.025	40%		
0.000	0%			0.002	10%			0.002	11%		
0.006	10%			0.000	0%			-0.006	-9%		
0.001	4%			0.001	3%			0.000	-1%		
-0.004	-4%			0.007	9%			0.011	14%		
-0.001	-5%			0.001	3%			0.002	8%		
-0.003	-3%			0.009	11%			0.012	15%		
0.000	1%			0.001	3%			0.000	2%		
-0.006	-7%			0.009	9%			0.016	17%		
-0.001	-2%			0.000	1%			0.001	3%		
-0.003	-2%			0.021	18%			0.024	20%		
0.000	-1%			0.001	4%			0.002	5%		
0.005	2%			0.008	4%			0.003	2%		
0.001	1%			0.001	1%			0.000	0%		
0.057	18%			-0.042	-13%			-0.099	-26%		
0.005	6%			-0.006	-6%			-0.011	-11%		
0.009	3%			-0.005	-2%			-0.013	-5%		
0.001	1%			-0.001	-2%			-0.002	-2%		
-0.014	-10%			0.027	20%			0.041	33%		
-0.002	-5%			0.002	4%			0.003	9%		
0.003	4%			0.010	15%			0.007	11%		
0.000	-2%			0.001	3%			0.001	5%		
-0.008	-12%			0.014	21%			0.022	37%		
-0.002	-9%			0.001	6%			0.003	15%		
0.013	6%			0.030	14%			0.040	18%		

Standard Deviation:

(continued)

Table C-2b (continued).

(Los Angeles, California)

Source No. 1 (20m x 20m)				Source No. 2 (40m x 10m)				Source No. 3 (10m x 40m)				Differences in UACs Sources No. 1 and No. 2		Differences in UACs Sources No. 1 and No. 3		Differences in UACs Sources No. 2 and No. 3	
Carteston Receptor Grid												Diff. In UAC		Diff. In UAC		Diff. In UAC	
X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		X (m)	Y (m)	UAC		% of Diff.		% of Diff.		% of Diff.	
-10	-10	3.225		-20	-5	3.241		-5	-20	2.674		1%		-0.551		-17%	
-5	-10	4.025		-10	-5	4.333		-2.5	-20	3.119		8%		-0.906		-23%	
0	-10	3.952		0	-5	4.297		0	-20	3.050		9%		-0.902		-23%	
5	-10	3.431		10	-5	3.871		2.5	-20	2.564		13%		-0.867		-25%	
10	-10	1.683		20	-5	1.592		5	-20	1.511		5%		-0.172		-10%	
10	-5	5.931		20	-2.5	4.787		5	-10	5.570		19%		-0.360		-6%	
10	0	6.636		20	0	5.882		5	0	5.644		11%		-0.992		-15%	
10	5	6.640		20	2.5	6.294		5	10	5.524		5%		-1.116		-17%	
10	10	5.600		20	5	5.866		5	20	4.325		5%		-1.275		-23%	
5	10	6.893		10	5	8.126		2.5	20	4.939		18%		-1.955		-28%	
0	10	6.860		0	5	8.285		0	20	4.913		21%		-1.947		-28%	
-5	10	6.031		-10	5	7.442		-2.5	20	4.156		23%		-1.875		-31%	
-10	10	3.393		-20	5	3.497		-5	20	2.702		3%		-0.691		-20%	
-10	5	5.649		-20	2.5	5.102		-5	10	5.015		10%		-0.634		-11%	
-10	0	5.944		-20	0	5.373		-5	0	5.167		10%		-0.777		-13%	
-10	-5	5.663		-20	-2.5	5.028		-5	-10	5.104		11%		-0.559		-10%	
-35	-35	0.124		-45	-30	0.139		-30	-45	0.095		16%		-0.029		-23%	
-17.5	-35	0.158		-22.5	-30	0.183		-15	-45	0.123		16%		-0.035		-22%	
0	-35	0.172		0	-30	0.199		0	-45	0.121		0%		-0.028		-19%	
17.5	-35	0.123		22.5	-30	0.124		15	-45	0.100		0%		-0.024		-2%	
35	-35	0.064		45	-30	0.053		30	-45	0.063		17%		-0.001		-2%	
35	-17.5	0.095		45	-15	0.076		30	-22.5	0.119		20%		0.024		25%	
35	0	0.592		45	0	0.377		30	0	0.696		36%		0.104		18%	
35	17.5	0.829		45	15	0.739		30	22.5	0.683		11%		-0.146		-18%	
35	35	0.192		45	30	0.304		30	45	0.101		58%		-0.091		-47%	
17.5	35	0.109		22.5	30	0.195		15	45	0.072		78%		-0.037		-34%	
0	35	0.125		0	30	0.144		0	45	0.100		15%		-0.025		-20%	
-17.5	35	0.113		-22.5	30	0.160		-15	45	0.077		42%		-0.035		-31%	
-35	35	0.139		-45	30	0.166		-30	45	0.089		19%		-0.050		-36%	
-35	17.5	0.387		-45	15	0.335		-30	22.5	0.370		14%		-0.017		-4%	
-35	0	0.603		-45	0	0.472		-30	0	0.603		22%		0.000		0%	
-35	-17.5	0.318		-45	-15	0.275		-30	-22.5	0.316		13%		-0.002		-1%	
Standard Deviation:												0.542	24%	0.614	15%	1.026	33%

C.3 Receptor Locations and Spacings

A sensitivity analysis was conducted using the ISCST3 model to determine what receptor locations and spacings should be used in the risk analysis for five types of waste management units (WMUs). A discussion of the analysis follows.

Because it takes a substantial amount of time for the ISCST3 model to execute, it was necessary to choose a limited number of receptors to be used in the dispersion modeling analysis. The larger the number of receptor points, the longer the run time. However, modeling fewer receptors may result in the omission of the maximum point for assessing exposure impacts. Therefore, a sensitivity analysis was conducted to determine the number of receptors needed for the model run and to locate ideal receptor placements.

A wind rose was plotted for each of the 29 meteorological stations to be used in the risk analysis for a 5-year time period in order to choose two meteorological stations for this sensitivity analysis. Little Rock, Arkansas, and Los Angeles, California, meteorological stations were selected for the sensitivity analysis. The wind roses show that Little Rock has very evenly distributed wind directions, and Los Angeles has a predominant southwest to west wind (Figure C-3). Little Rock and Los Angeles were chosen to determine if a higher density of receptors should be placed downwind of a site near Los Angeles, as compared to a site near Little Rock. Similarly, the 5th, 50th, and 95th percentile of sizes of LAUs were used in the sensitivity analysis to determine whether sizes of units can affect receptor locations and spacings. The areas of the 5th, 50th, and 95th percentile of sizes of LAUs are 1,200 m², 100,000 m², and 1,700,000 m², respectively.

The dispersion modeling was conducted using two sets of receptor grids. The first set of receptor points (Cartesian receptor grid) was placed around the modeled source with distances of 0, 25, 50, 75, and 150 meters from the edge of the unit. Square-shaped ground-level area sources were used in the modeling. Therefore, these receptors are located on five squares surrounding the source. The second set of receptor points (polar receptor grid) was placed outside of the first set of receptors to 10 kilometers from the center of the source. Since the ISCST3 model's area source algorithm does not consider elevated terrain, receptor elevations were not input in the modeling.

In this sensitivity analysis, both downwind and lateral receptor spacings were investigated for three unit sizes using 5 years of meteorological data from Little Rock and Los Angeles. For the first set of receptor points (i.e., Cartesian receptor grid), five downwind distances of 0, 25, 50, 75, and 150 meters from the edge of the source were used. For lateral receptor spacing, choices of 64, 32, and 16 equally spaced receptor points for each square were used in the modeling to determine the number of receptors needed to catch the maximum impacts. (See Figures C-5a through C-5c for Cartesian receptor locations and spacings [50th percentile]). For the second set of receptor points (i.e., polar receptor grid), about 20 downwind distances (i.e., receptor rings) were used. Receptor lateral intervals of 22.5° and 10° were used to determine whether 22.5° spacing can catch the maximum impacts. With a 22.5° interval, there are 16 receptors on each ring. There are 36 receptors on each ring for the 10° interval. See Figures C-6a and C-6b for polar receptor locations (5th percentile).

The results (Figures C-7a through C-7f) show that the maximum downwind concentrations decrease sharply from the edge of the area source to 150 meters from the source. The maximum concentrations decrease more sharply for a smaller area source than for a larger one. This means that more close-to-source receptors are generally needed for a small area source than for a large one.

The results also show that the maximum impacts are generally higher for a dense receptor grid (i.e., 64 or 32 receptors on each square) than for a scattered receptor grid (i.e., 16 receptors on each square). However, the differences of the maximum receptor impacts are not significant between a dense and a scattered receptor grid (Figures C-7a through C-7f). It should be noted that the above conclusions apply to both Little Rock and Los Angeles. This means that the distribution of wind directions does not play an important role in determining receptor lateral spacings.

Figures C-8a through C-8f compare the maximum concentrations at each ring for 22.5° and 10° intervals. The results show that the differences of the maximum concentrations are greater for close-to-source receptors than for further out receptors, and the differences are greater for larger area sources than for smaller area sources. The differences of the maximum concentrations for 22.5° and 10° intervals are generally small, and the concentrations tend to be the same at 10 kilometers. The conclusions were drawn from both Little Rock and Los Angeles meteorological data.

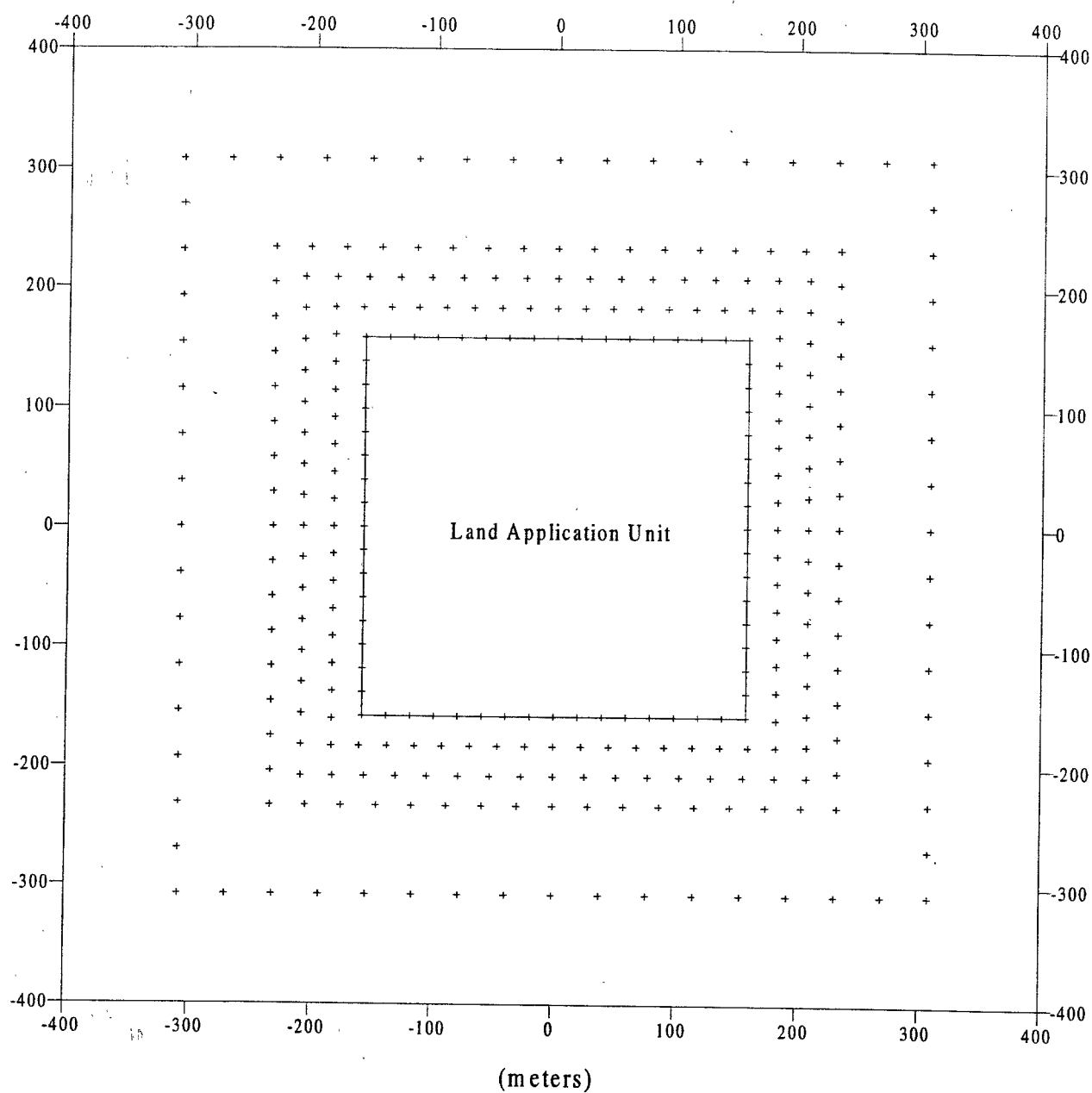


Figure C-5a. Cartesian Receptor Grid (64 receptors each square)

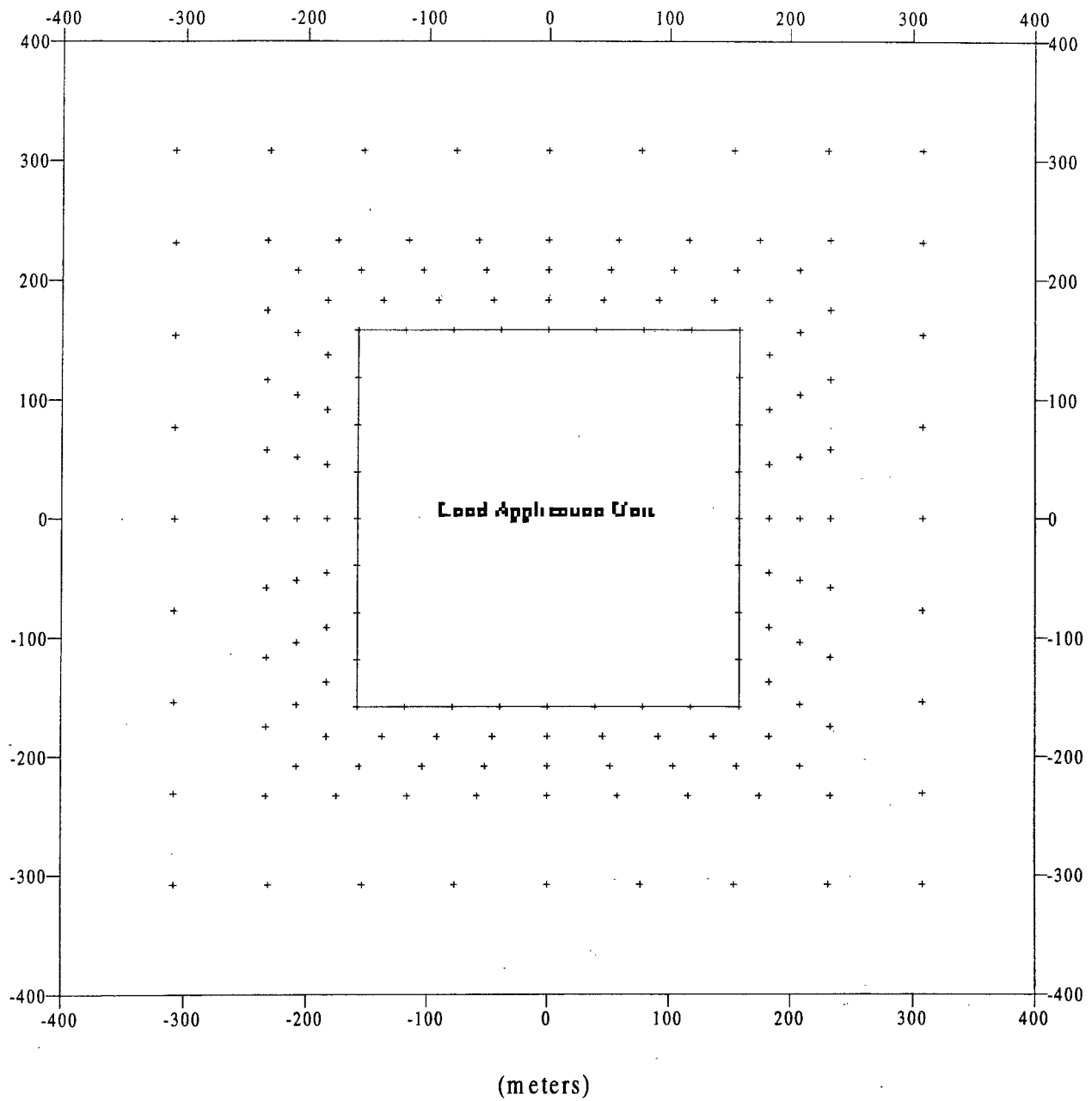


Figure C-5b. Cartesian Receptor Grid (32 receptors each square)

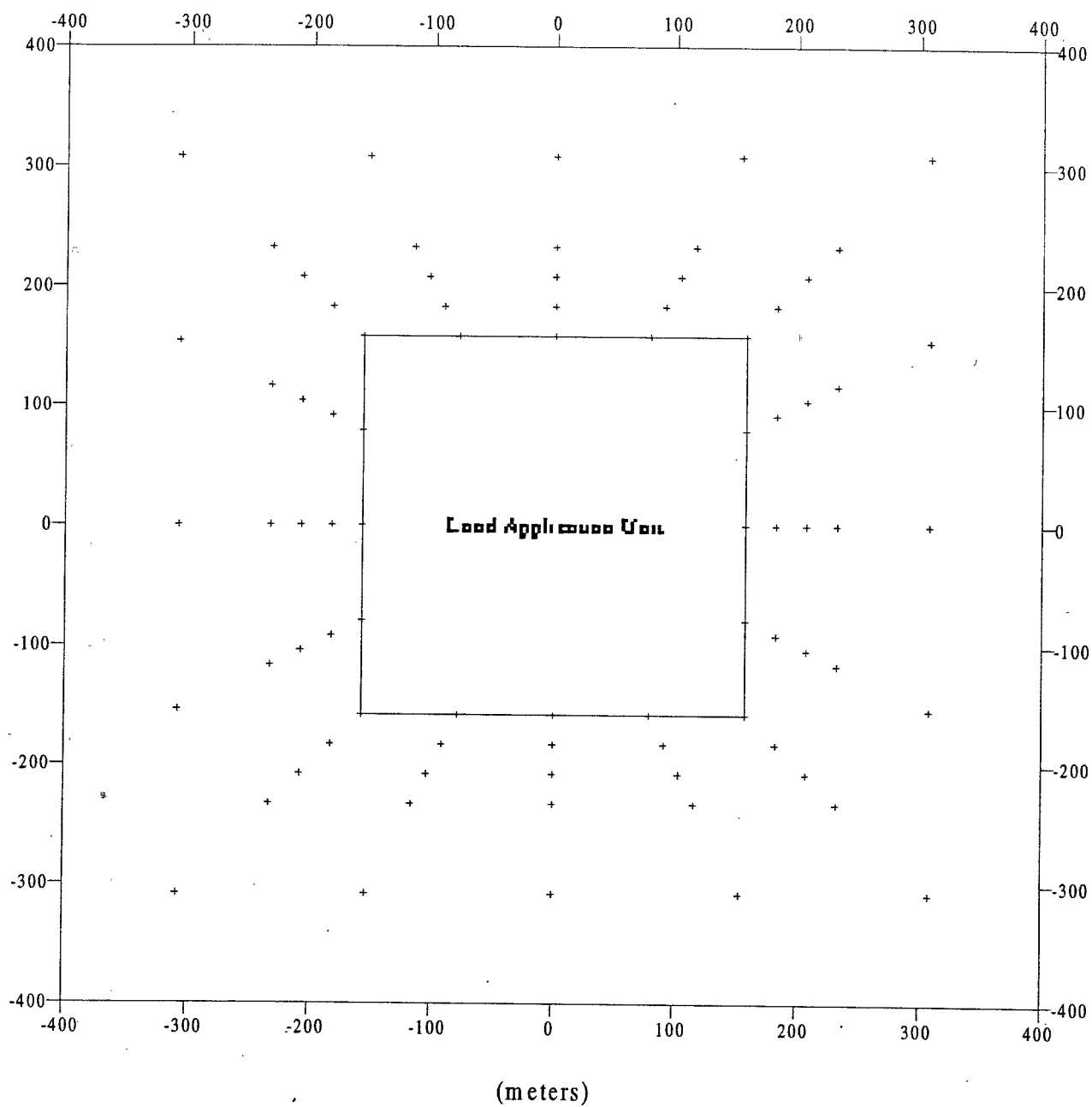


Figure C-5c. Cartesian Receptor Grid (16 receptors each square)

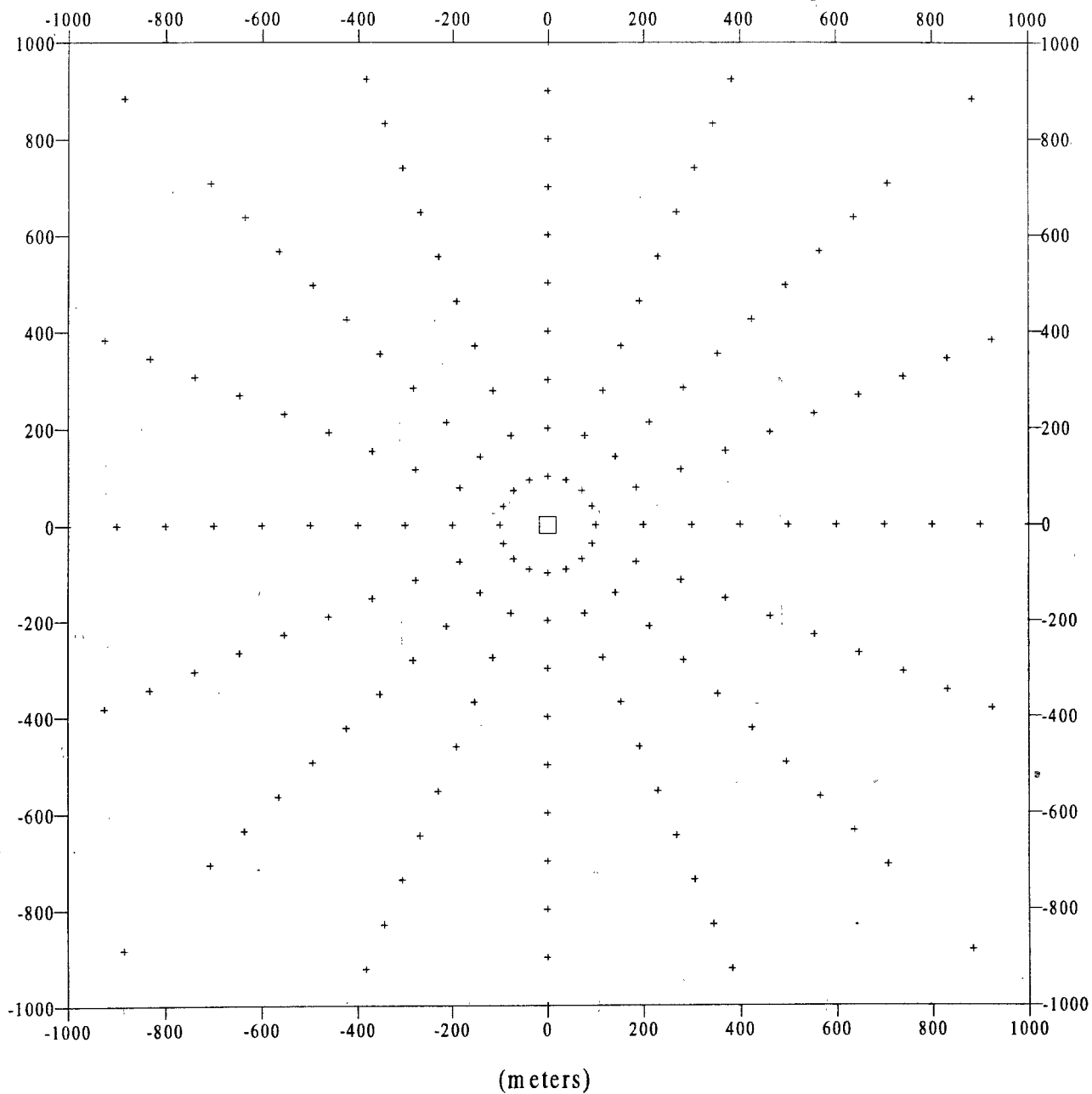


Figure C-6a. Polar Receptor Grid (22.5 degree)

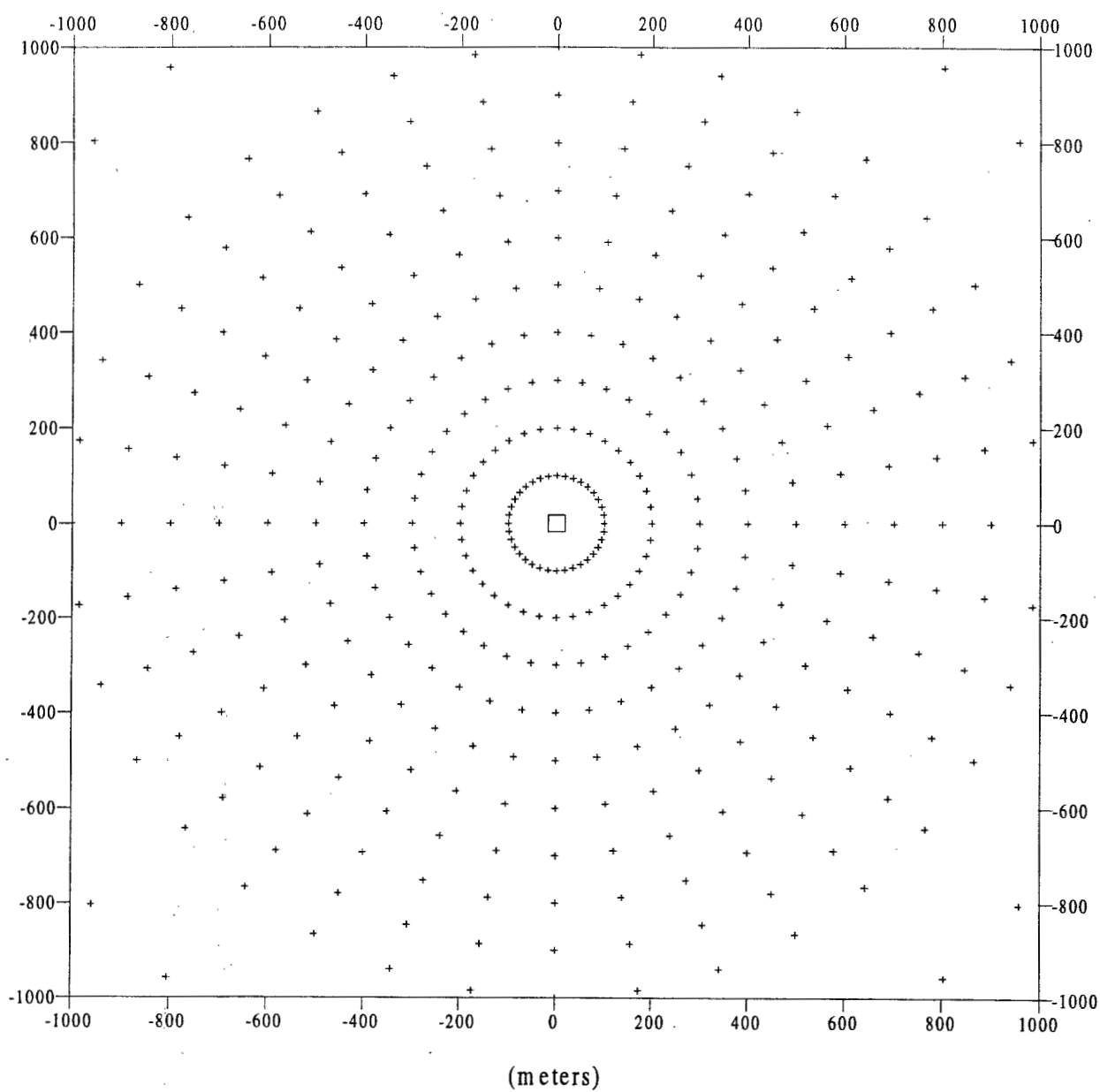


Figure C-6b. Polar Receptor Grid (10 degree)

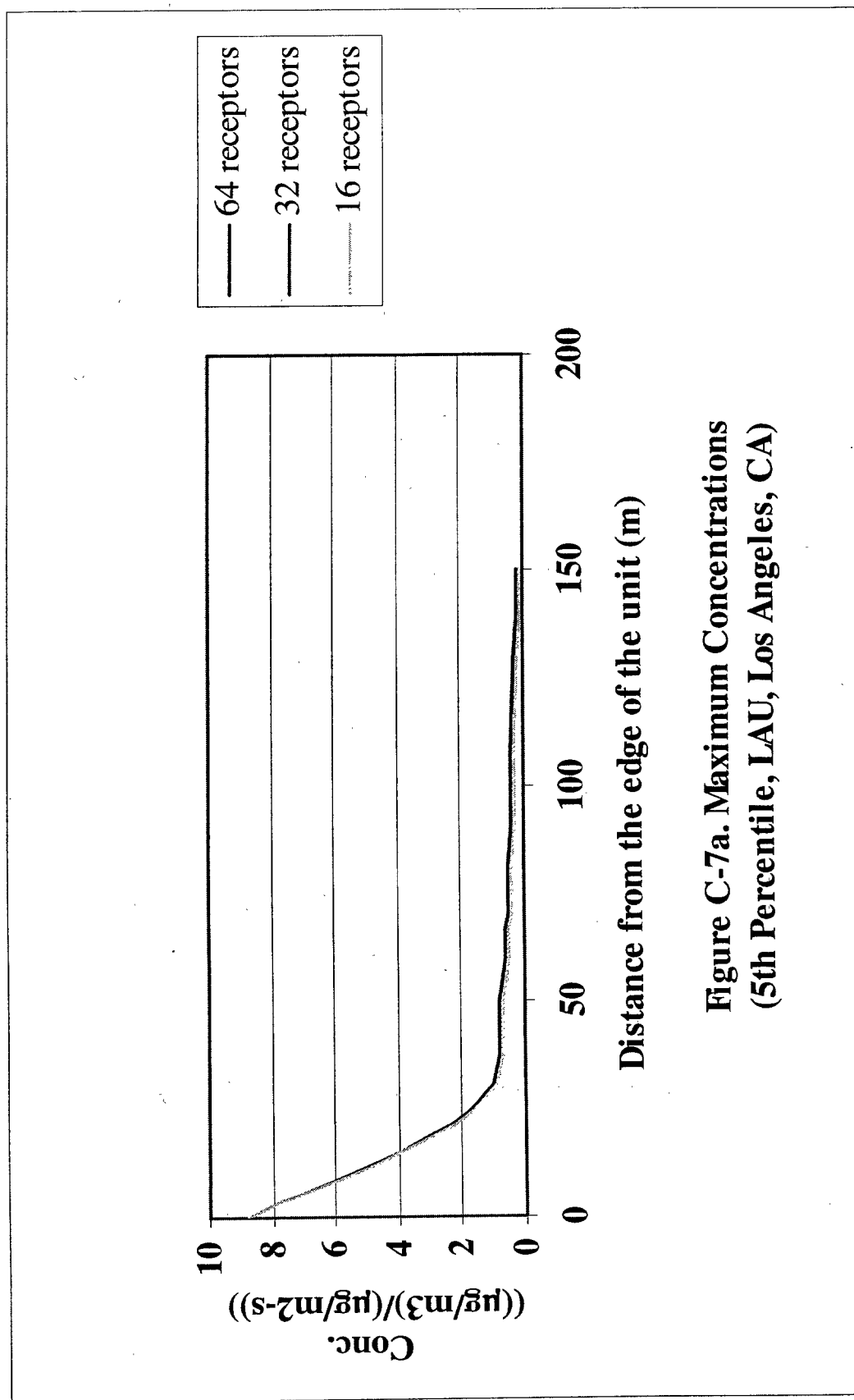
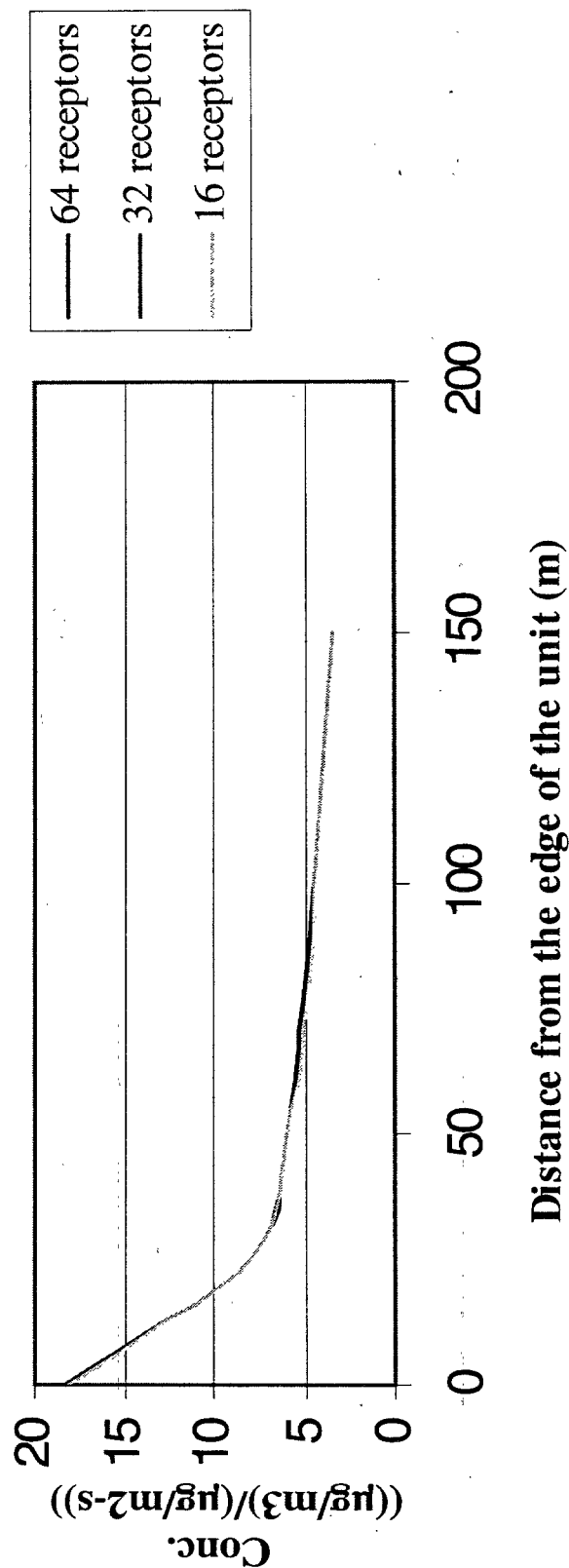
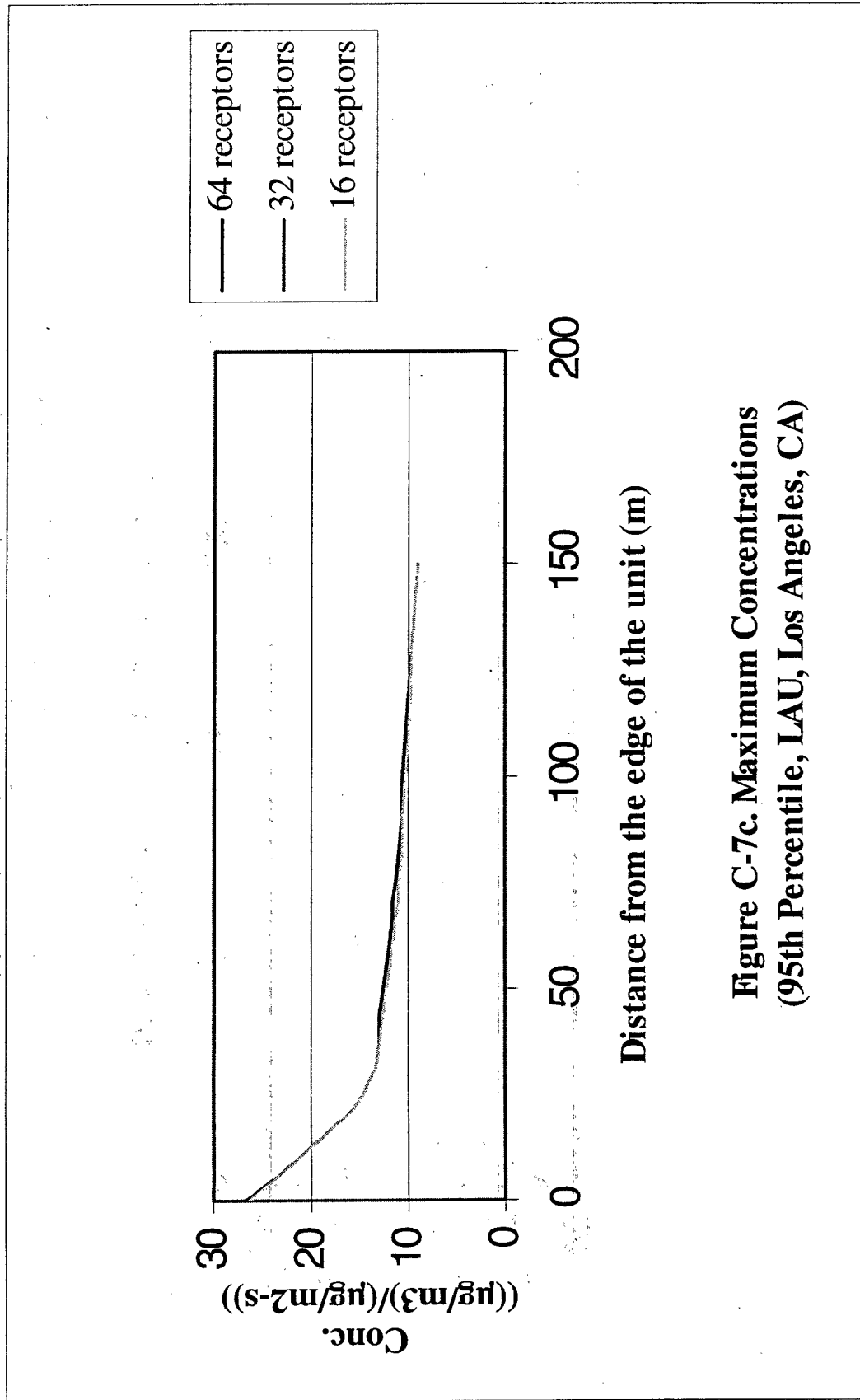


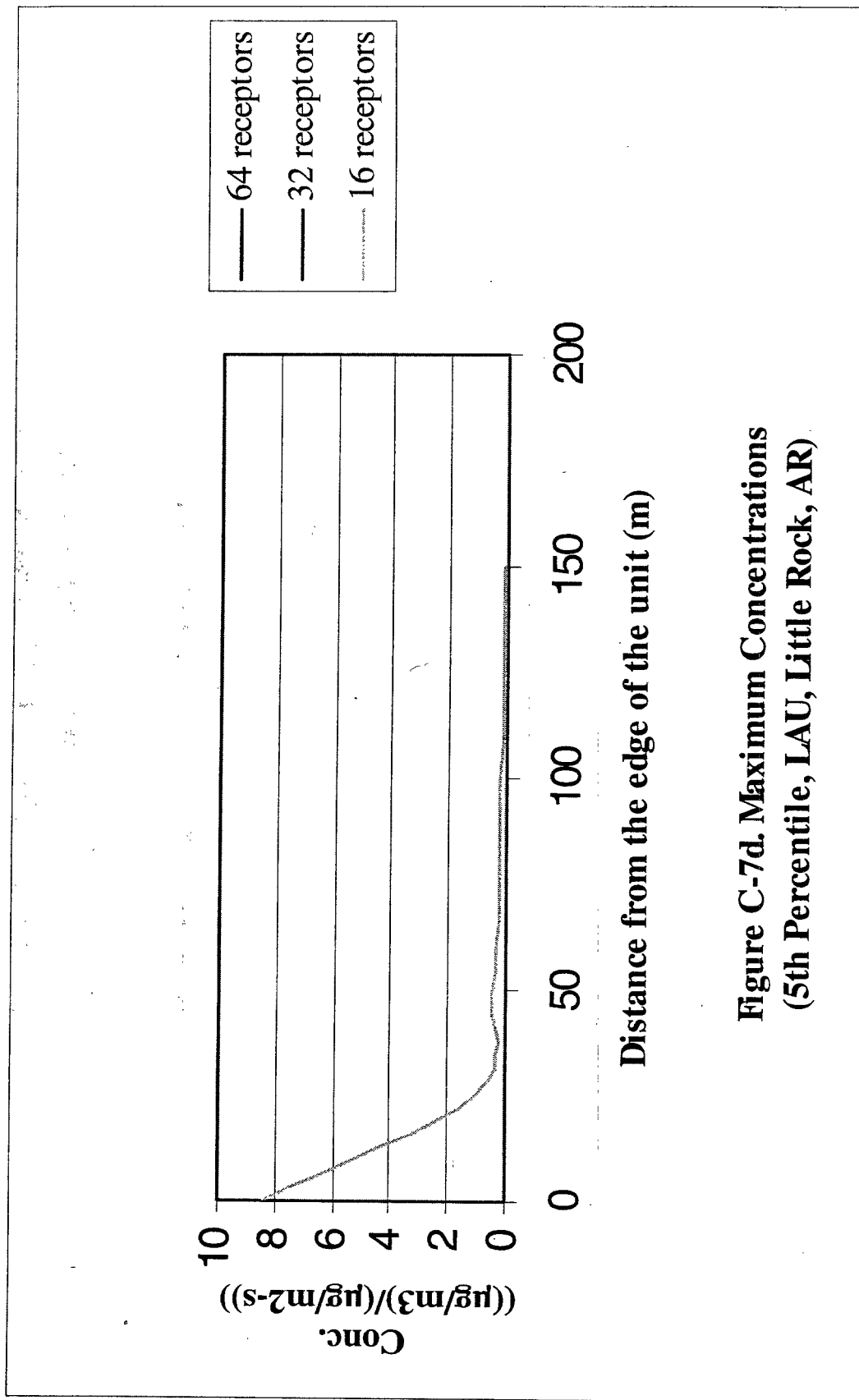
Figure C-7a. Maximum Concentrations
(5th Percentile, LAU, Los Angeles, CA)



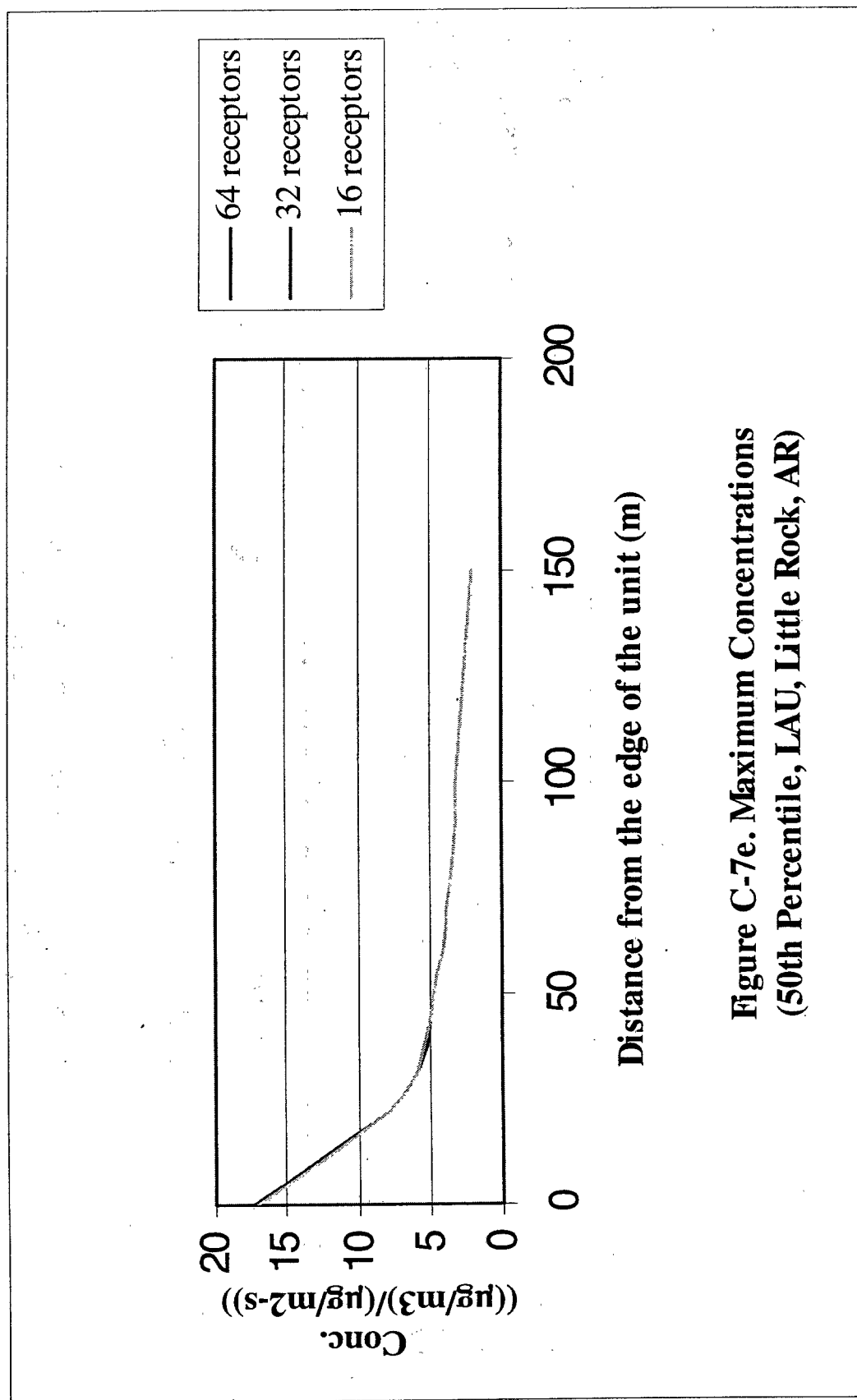
**Figure C-7b. Maximum Concentrations
(50th Percentile, LAU, Los Angeles, CA)**



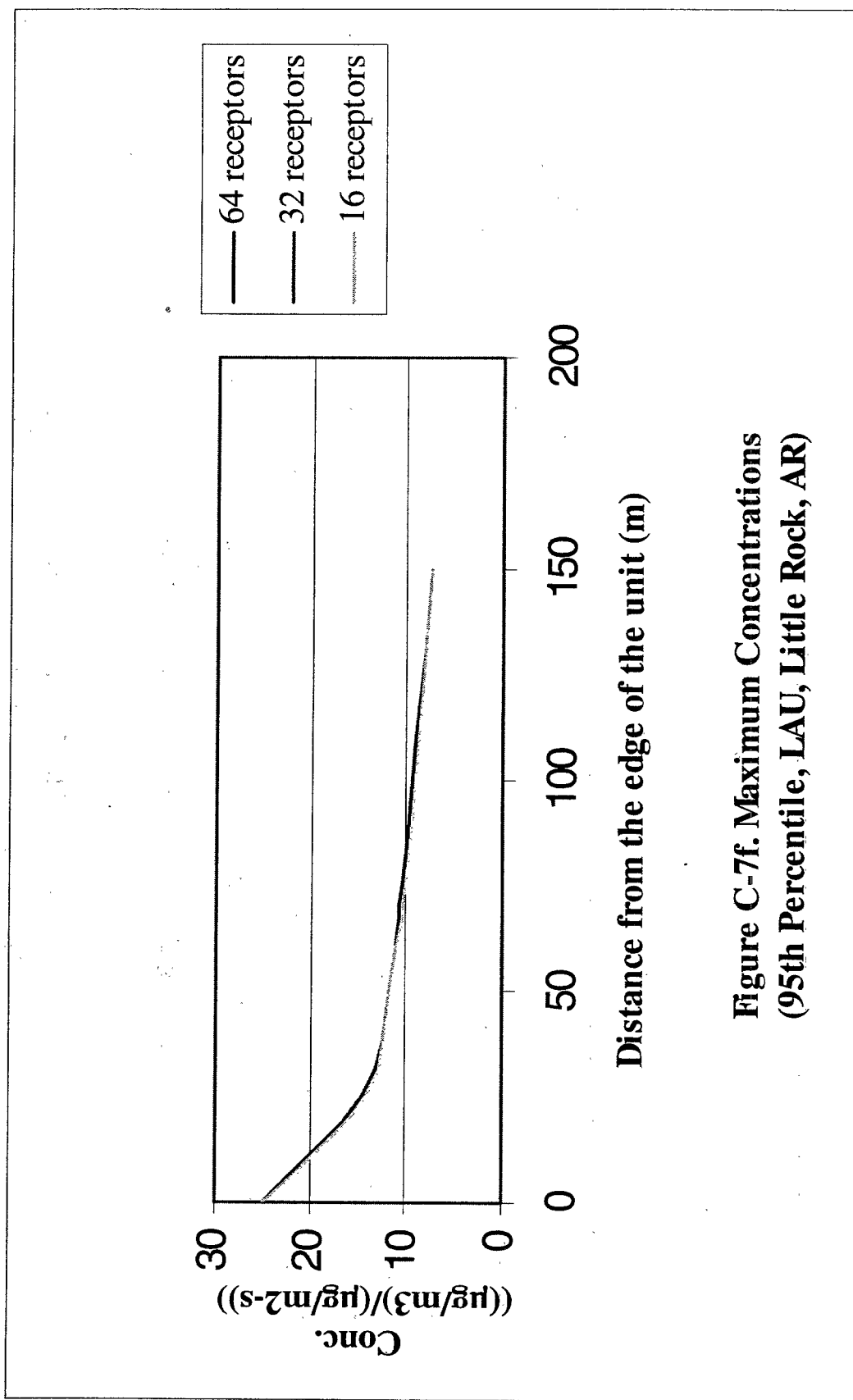
**Figure C-7c. Maximum Concentrations
(95th Percentile, LAU, Los Angeles, CA)**



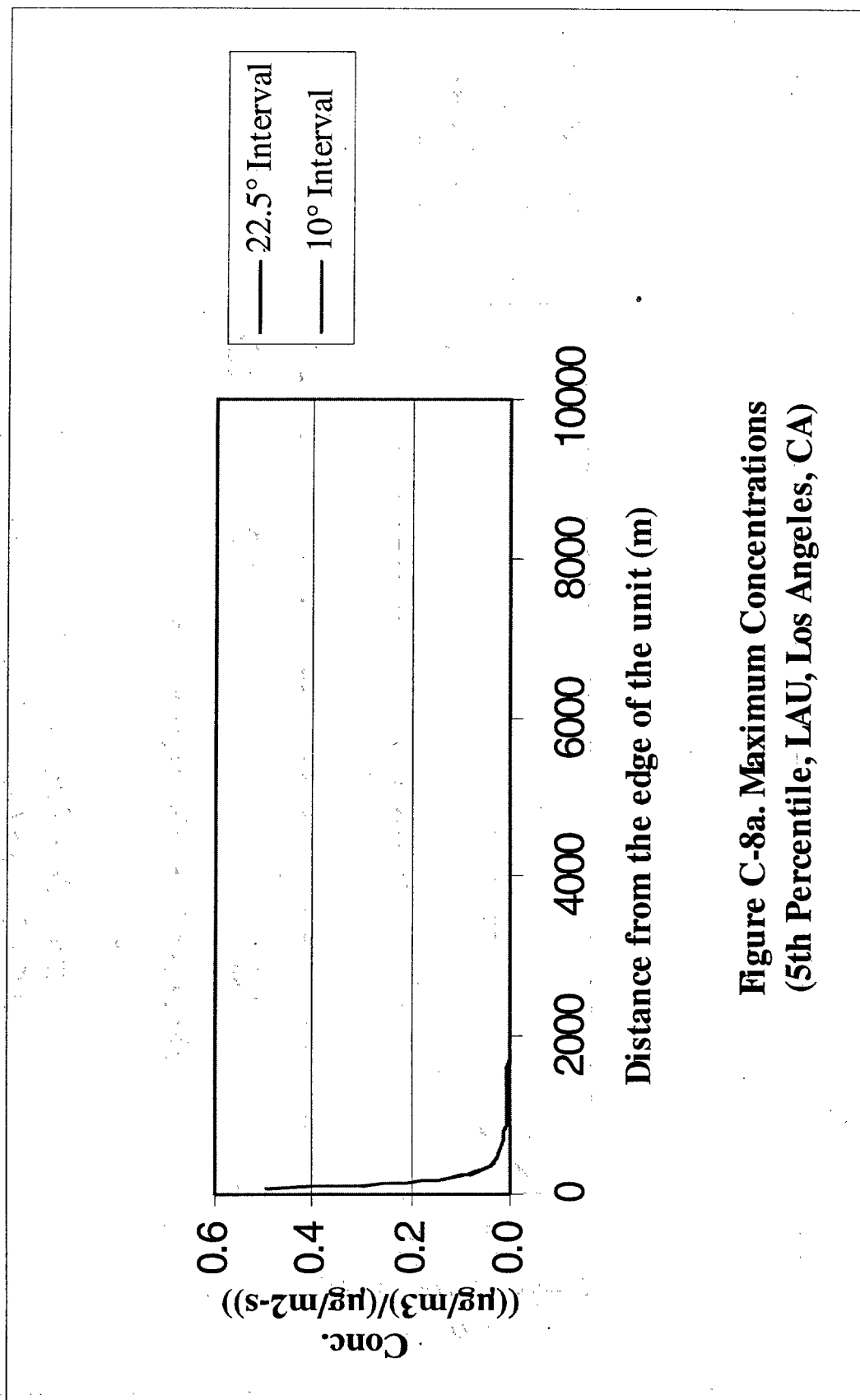
**Figure C-7d. Maximum Concentrations
(5th Percentile, LAU, Little Rock, AR)**



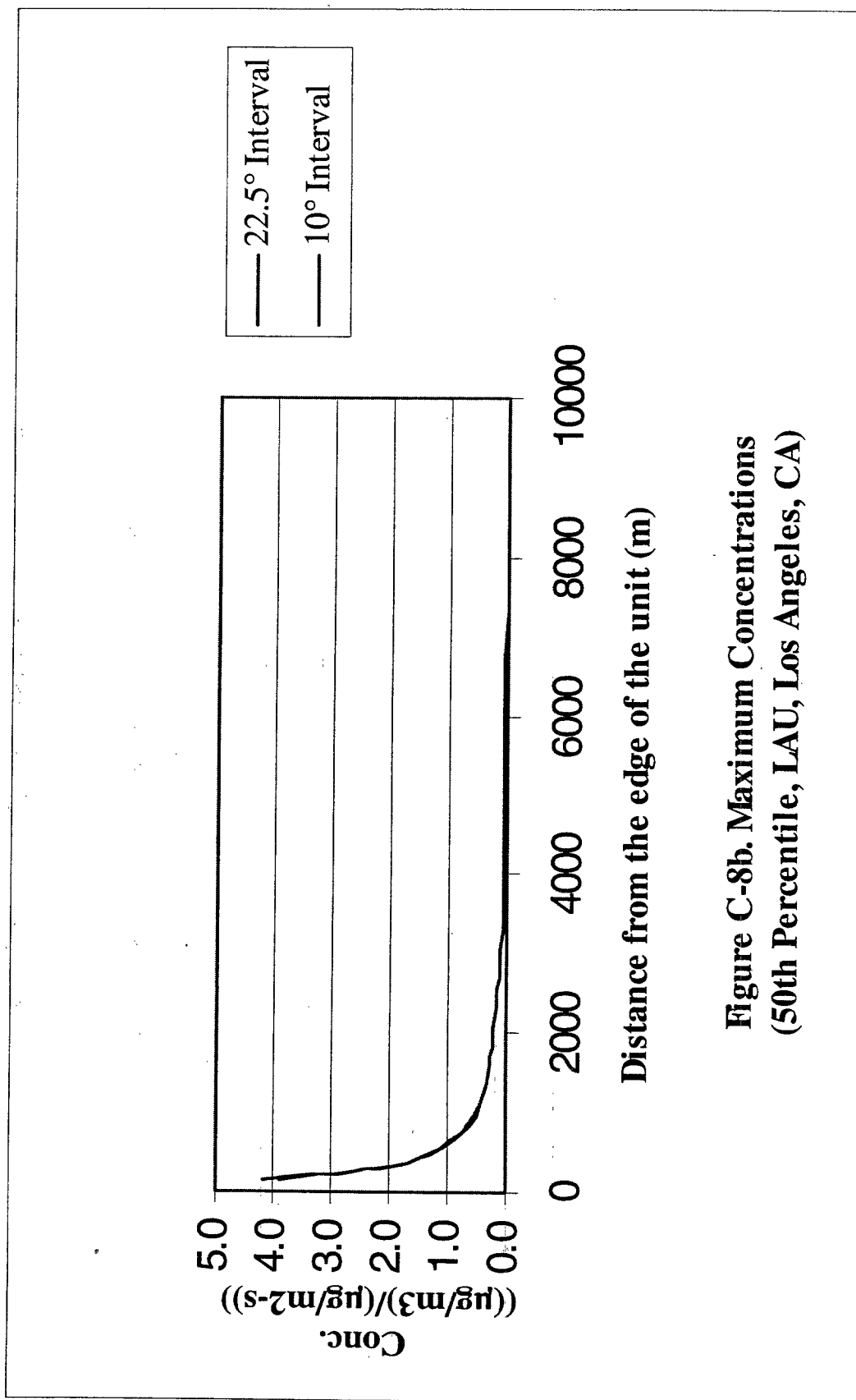
**Figure C-7e. Maximum Concentrations
(50th Percentile, LAU, Little Rock, AR)**



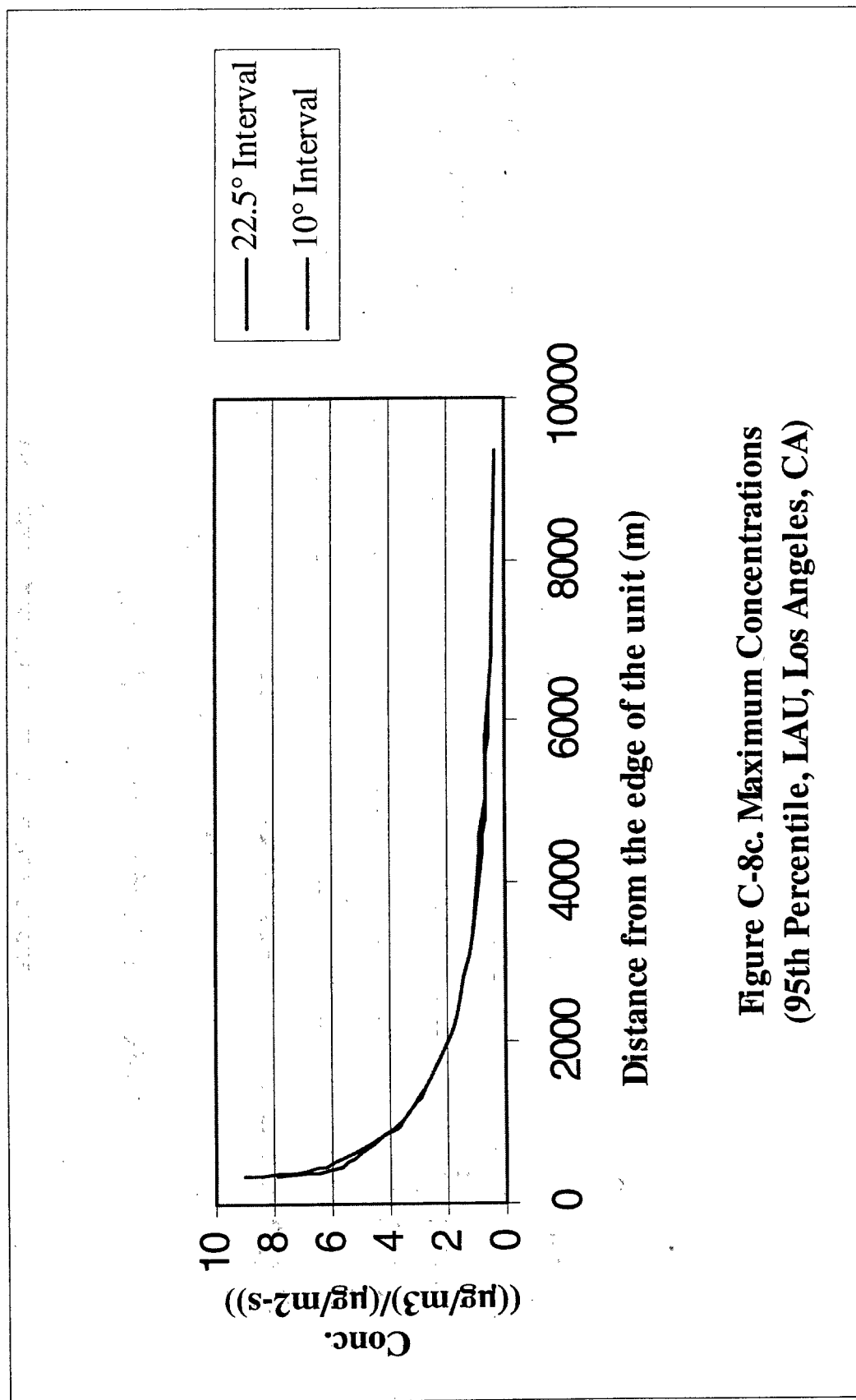
**Figure C-7f. Maximum Concentrations
(95th Percentile, LAU, Little Rock, AR)**



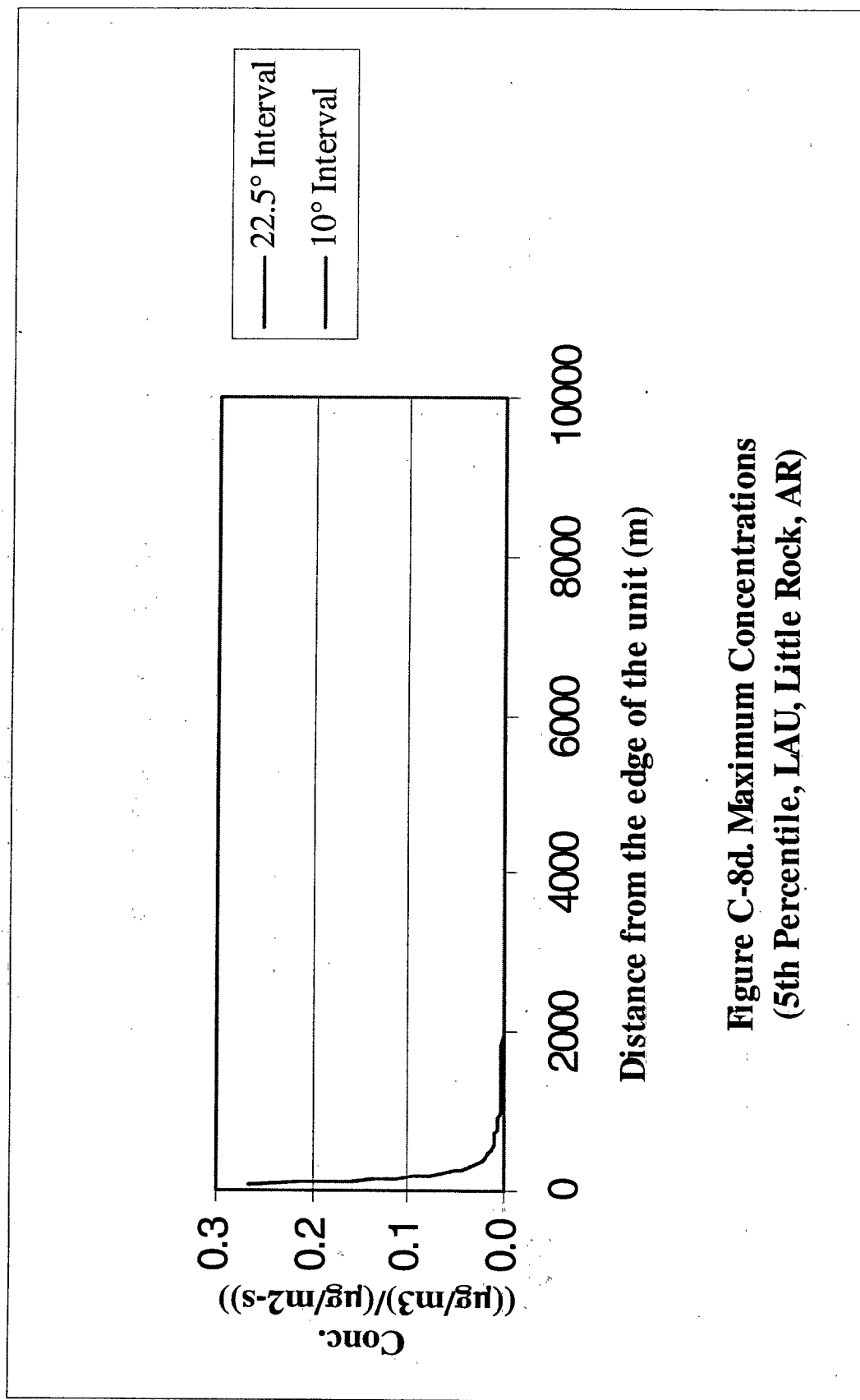
**Figure C-8a. Maximum Concentrations
(5th Percentile, LAU, Los Angeles, CA)**



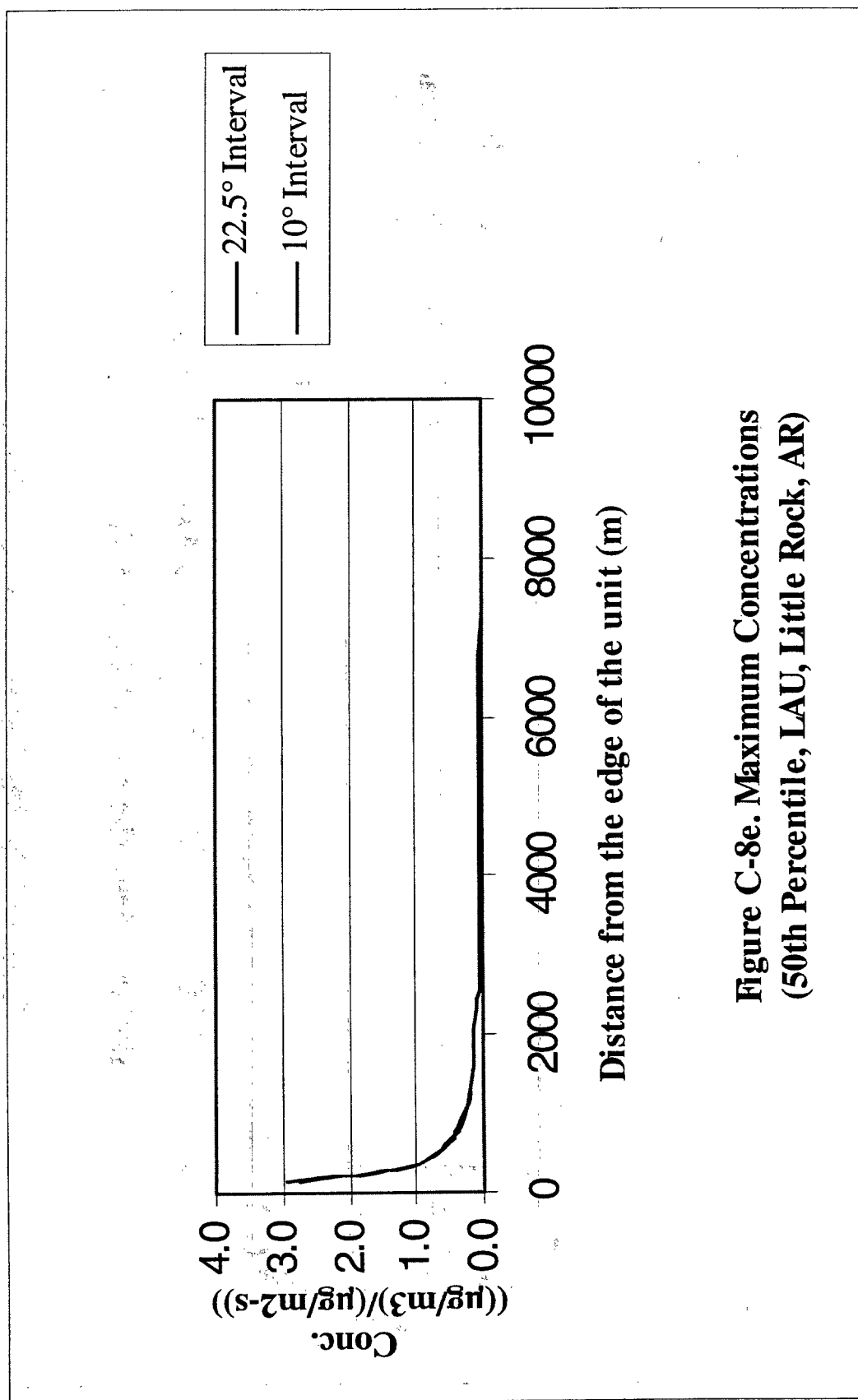
**Figure C-8b. Maximum Concentrations
(50th Percentile, LAU, Los Angeles, CA)**



**Figure C-8c. Maximum Concentrations
(95th Percentile, LAU, Los Angeles, CA)**



**Figure C-8d. Maximum Concentrations
(5th Percentile, LAU, Little Rock, AR)**



**Figure C-8e. Maximum Concentrations
(50th Percentile, LAU, Little Rock, AR)**

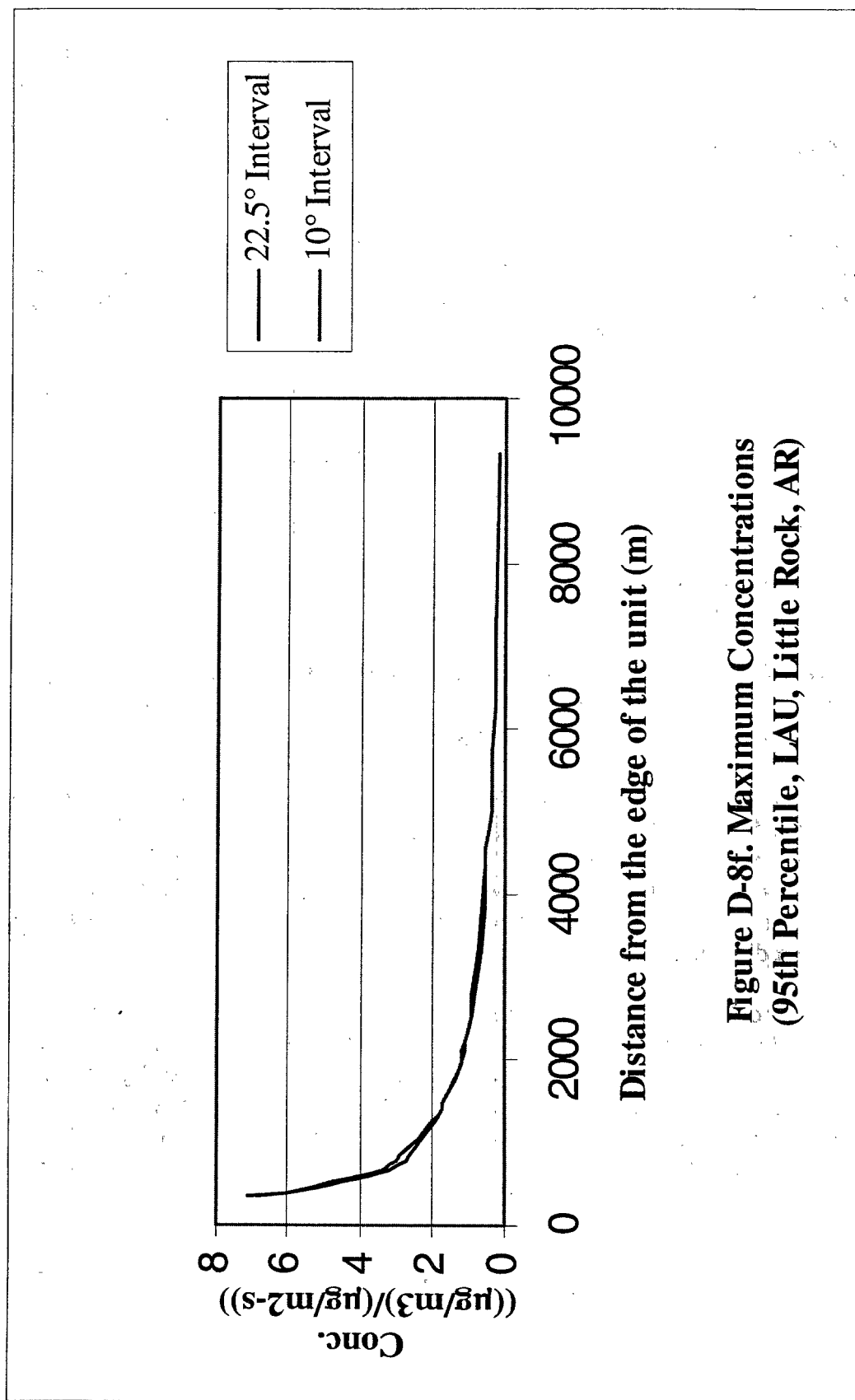


Figure D-8f. Maximum Concentrations
(95th Percentile, LAU, Little Rock, AR)

C.4 An Analysis on Windroses at the 29 Sites

The hourly meteorological data from the 29 meteorological stations used in the Air Characteristic Study were used to generate windroses. A windrose consists of 16 directions, with the angle between any two adjacent directions being 22.5° . The prevailing wind directions for the 29 meteorological stations were counted to estimate the number of entries in each wind directions category. The results are presented in Figure C-9.

The narrowness of the most frequent wind directions for each of the 29 meteorological stations was examined. Based on the narrowness (or angles) of the most frequent wind directions, four categories were used to distinguish the windroses for the 29 meteorological stations. The four categories of windroses are:

- Narrowly distributed: most frequent wind directions no greater than 45°
- Moderately distributed: most frequent wind directions no greater than 90°
- Evenly distributed: no obvious predominant wind directions
- Bimodally distributed: most frequent wind directions are from two opposite directions.

The number of meteorological stations in each category is given in Table C-3. Figure C-10 gives some examples of windroses for each category. The windroses for the 29 meteorological stations are available and can be provided upon request.

An examination of the windroses and the maximum unitized annual average air concentrations from the Air Characteristic Study revealed that the sites with high concentrations are those with narrowly distributed wind directions. Simply put, persistent wind direction consistently blows pollutants from the source to the same receptors. Therefore, the more often the wind blows in a certain direction, the more likely high cumulative concentrations will occur at sites in that direction.

Air concentrations from a source are inversely proportion to windspeed. Given the same distribution of wind directions, a site with lower windspeed will have higher concentrations. The windroses show that, in the prevailing wind direction, the percentage of light wind occurring at a site with narrowly distributed wind directions is often higher than that at a site with evenly distributed wind directions. Therefore, we can conclude that a site with narrowly distributed wind directions will most likely produce the highest long-term average air concentrations.

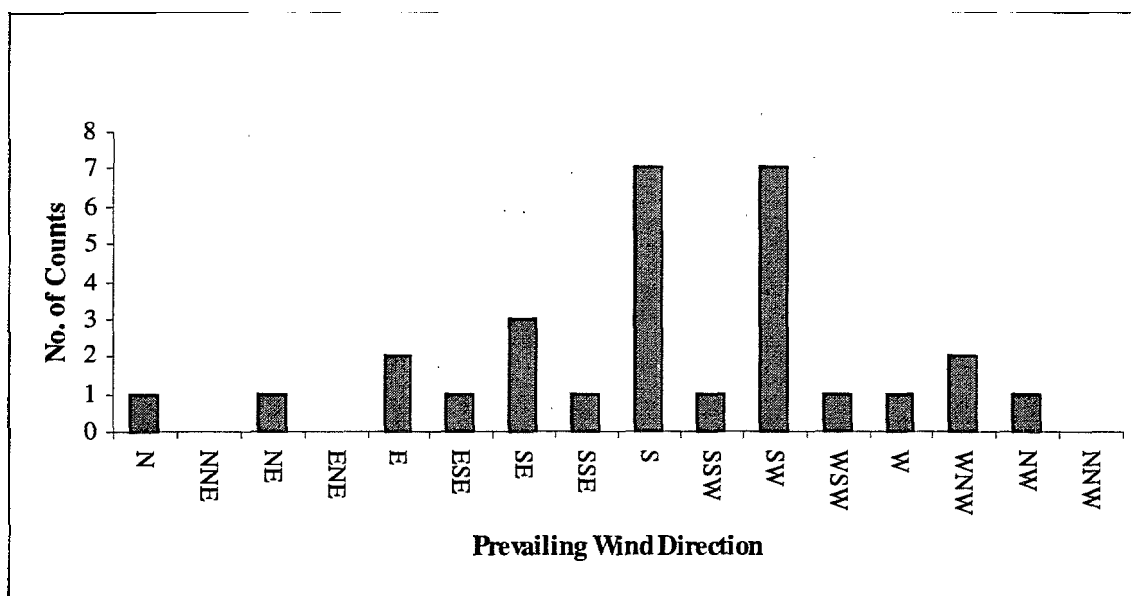
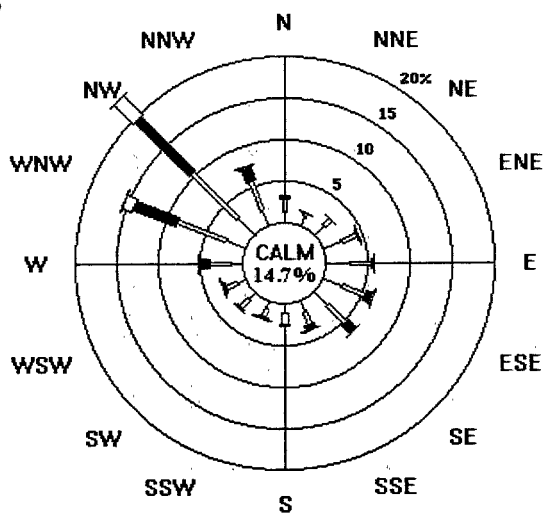
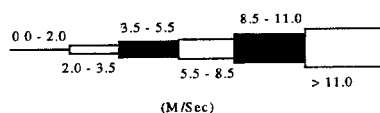


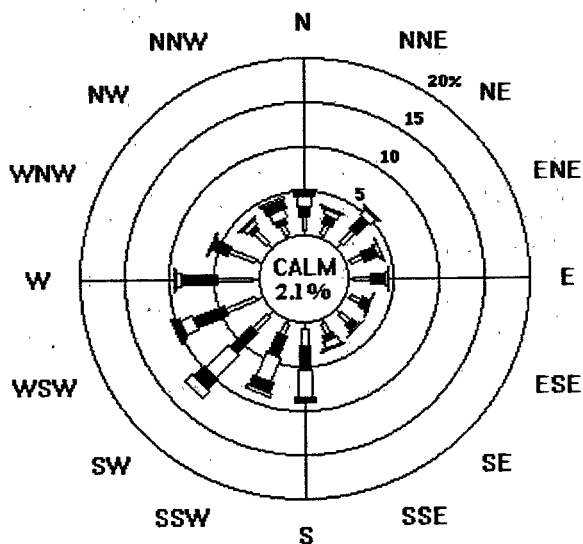
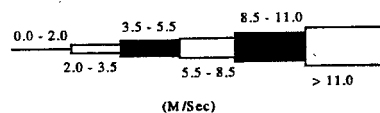
Figure C-9. Counts Prevailing Wind Directions in Each Direction

Table C-3. No. of Met Stations with Different Shapes of Windroses

Shape of Windrose	No. of Stations
Narrowly distributed	10
Moderately distributed	4
Evenly distributed	6
Bi-modally distributed	9

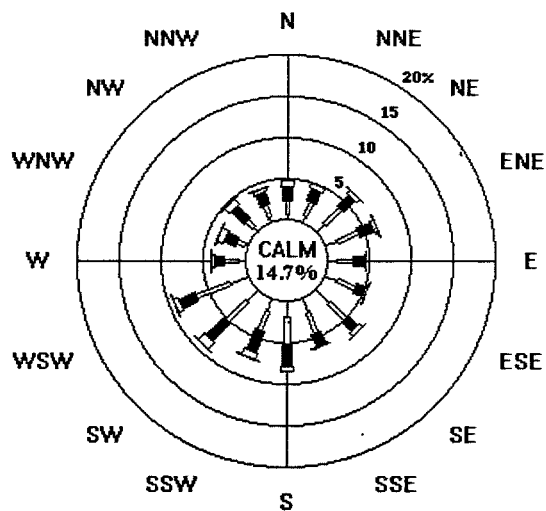
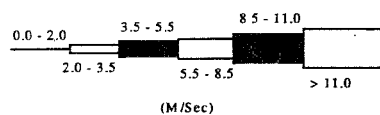


Narrowly Distributed Windrose

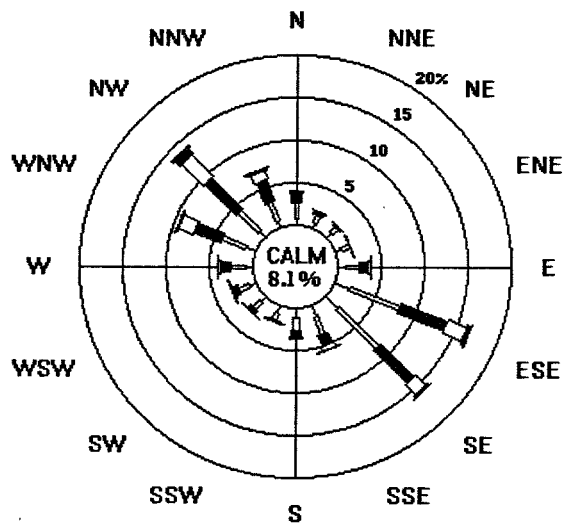
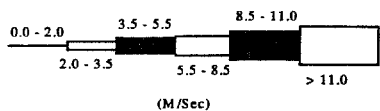


Moderately Distributed Windroses

Figure C-10. Examples of Different Shapes of Windroses



Evenly Distributed Windrose



Bi-modally Distributed Windrose

Figure C-10 (continued).

Appendix D

Determination of Groundwater Dilution Attenuation Factors for Fixed Waste Site Areas using EPACMTP

Note: This appendix consists of Attachment E from the *Technical Background Document for Soil Screening Guidance* (U.S. EPA, 1995). The entire attachment is included to document the determination of DAFs used in the solvent wipers risk analysis.

**DETERMINATION OF GROUNDWATER
DILUTION ATTENUATION FACTORS
FOR FIXED WASTE SITE AREAS
USING EPACMTP**

BACKGROUND DOCUMENT

EPA OFFICE OF SOLID WASTE

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PREFACE

The work documented in this report was conducted by HydroGeoLogic, Inc. for the EPA Office of Solid Waste. The work was performed partially under Contract No. 68-W0-0029 and partially under Contract No. 68-W3-0008, subcontracted through ICF Inc. This documentation was prepared under Contract No. 68-W4-0017. Technical direction on behalf of the Office of Solid Waste was provided by Dr. Z.A. Saleem.

ABSTRACT

The EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP) was applied to generate Dilution Attenuation Factors (DAF) for the groundwater pathway in support of the development of Soil Screening Level Guidance. The model was applied on a nationwide basis, using Monte Carlo simulation, to determine DAFs as a function of the area of the contaminated site at various probability levels. The analysis was conducted in two stages: First, the number of Monte Carlo iterations required to achieve converged results was determined. Convergence was defined as a change of less than 5% in the 85th percentile DAF value. A number of 15,000 Monte Carlo iterations was determined to yield convergence; subsequent analyses were performed using this number of iterations. Second, Monte Carlo analyses were performed to determine DAF values as a function of the contaminated area. The effects of different placements of the receptor well were evaluated.

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1.0 INTRODUCTION

The Agency is developing estimates for threshold values of chemical concentrations in soils at contaminated sites that represent a level of concentration above which there is sufficient concern to warrant further site-specific study. These concentration levels are called Soil Screening Levels (SSLs). The primary purpose of the SSLs is to accelerate decision making concerning contaminated soils. Generally, if contaminant concentrations in soil fall below the screening level and the site meets specific residential use conditions, no further study or action is warranted for that area under CERCLA (EPA, 1993b).

The Soil Screening Levels have been developed using residential land use human exposure assumptions and considering multiple pathways of exposure to the contaminants, including migration of contaminants through soil to an underlying potable aquifer. Contaminant migration through the unsaturated zone to the water table generally reduces the soil leachate concentration by attenuation processes such as adsorption and degradation. Groundwater transport in the saturated zone further reduces concentrations through attenuation and dilution. The contaminant concentration arriving at a receptor point in the saturated zone, e.g., a domestic drinking water well, is therefore generally lower than the original contaminant concentration in the soil leachate.

The reduction in concentration can be expressed succinctly in a Dilution-Attenuation Factor (DAF) defined as the ratio of original soil leachate concentration to the receptor point concentration. The lowest possible value of DAF is therefore one; a value of $DAF=1$ means that there is no dilution or attenuation at all; the concentration at the receptor point is the same as that in the soil leachate. High values of DAF on the other hand correspond to a high degree of dilution and attenuation.

For any specific site, the DAF depends on the interaction of a multitude of site-specific factors and physical and bio-chemical processes. The DAF also depends on the nature of the contaminant itself; i.e., whether or not the chemical degrades or sorbs. As a result, it is impossible to predict DAF values without the aid of a suitable computer fate and transport

simulation model that simulates the migration of a contaminant through the subsurface, and accounts for the relevant mechanisms and processes that affect the receptor concentration.

The Agency has developed the EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP; EPA, 1993a, 1994) to assess the groundwater quality impacts due to migration of wastes from surface waste sites. This model simulates the fate and transport of contaminants after their release from the land disposal unit into the soil, downwards to the water table and subsequently through the saturated zone. The fate and transport model has been coupled to a Monte Carlo driver to permit determination of DAFs on a generic, nationwide basis. The EPACMTP model has been applied to determine DAFs for the subsurface pathway for fixed waste site areas, as part of the development of Soil Screening Levels. This report describes the application of EPACMTP for this purpose.

2.0 GROUNDWATER MODEL

2.1 Description of EPACMTP Model

The EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP, EPA, 1993a, 1994) is a computer model for simulating the subsurface fate and transport of contaminants that are released at or near the soil surface. A schematic view of the conceptual subsurface system as simulated by EPACMTP, is shown in Figure 1. The contaminants are initially released over a rectangular source area representing the waste site. The modeled subsurface system consists of an unsaturated zone underneath the source area, and an underlying water table aquifer. Contaminants move vertically downward through the unsaturated zone to the water table. The contaminant is assumed to be dissolved in the aqueous phase; it migrates through the soil under the influence of downward infiltration. The rate of infiltration may reflect the combined effect of precipitation and releases from the source area. Once the contaminant enters the saturated zone, a three-dimensional plume develops under the combined influence of advection with the ambient groundwater flow and dispersive mixing.

The EPACMTP accounts for the following processes affecting contaminant fate and transport: advection, dispersion, equilibrium sorption, first-order decay reactions, and recharge dilution in the saturated zone. For contaminants that transform into one or more daughter products, the model can account for the fate and transport of those transformation products also.

The EPACMTP model consists of three main modules:

- An unsaturated zone flow and transport module
- A saturated zone flow and transport module
- A Monte Carlo driver module, which generates model input parameter values from specified probability distributions

The assumptions of the unsaturated zone and saturated zone flow and transport modules are described in Section 2.2. The Monte Carlo modeling procedure is described in Section 2.3.

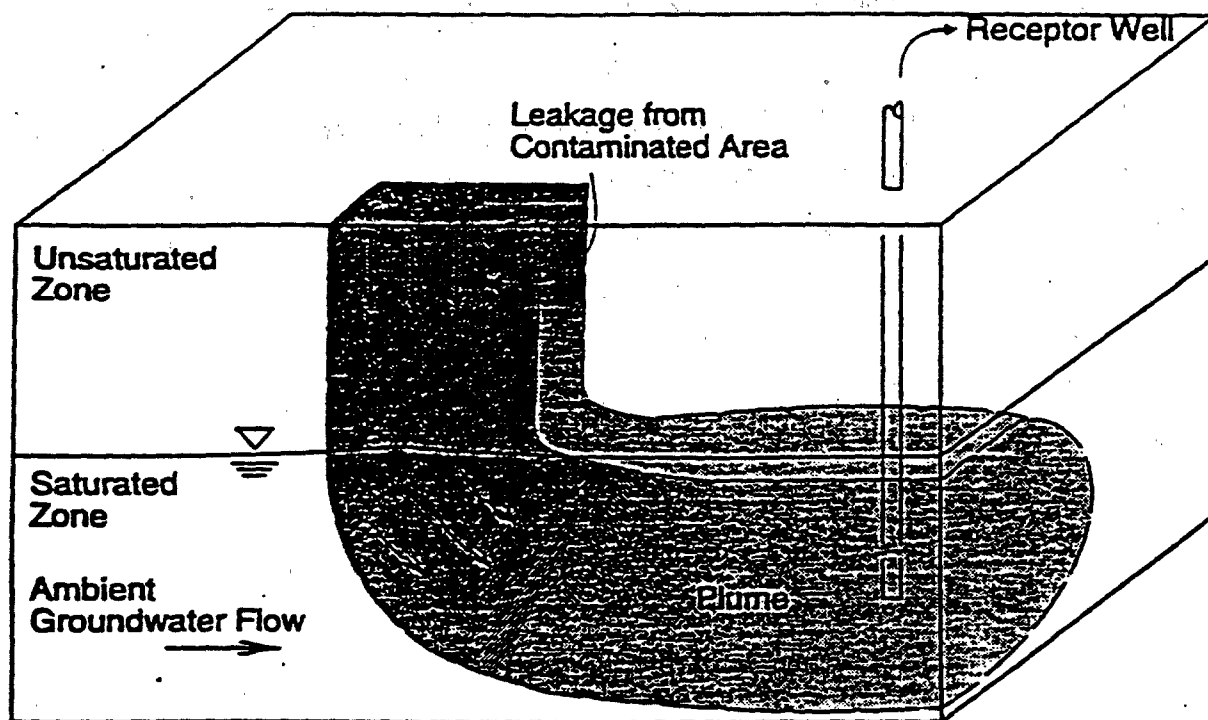


Figure 1 Conceptual view of the unsaturated zone-saturated zone system simulated by EPACMTP.

2.2 Fate and Transport Simulation Modules

2.2.1 Unsaturated zone flow and transport module

Details on the mathematical formulation and solution techniques of the unsaturated zone flow and transport module are provided in the EPACMTP background document (EPA, 1993a). For completeness, the major features and assumptions are summarized below:

- The source area is a rectangular area.
- Contaminants are distributed uniformly over the source area.
- The soil is a uniform, isotropic porous medium.
- Flow and transport in the unsaturated zone are one-dimensional, downward.
- Flow is steady state, and driven by a prescribed rate of infiltration.
- Flow is isothermal and governed by Darcy's Law.
- The leachate concentration entering the soil is either constant (with a finite or infinite duration), or decreasing with time following a first-order decay process.
- The chemical is dilute and present in solution or soil solid phase only.
- Sorption of chemicals onto the soil solid phase is described by a linear or nonlinear (Freundlich) equilibrium isotherm.
- Chemical and biological transformation process can be represented by an effective, first-order decay coefficient.

2.2.2 Saturated zone flow and transport module

The unsaturated zone module computes the contaminant concentration arriving at the water table, as a function of time. Multiplying this concentration by the rate of infiltration through the unsaturated zone yields the contaminant mass flux entering the saturated zone. This mass flux is specified as the source boundary condition for the saturated zone flow and transport module.

Groundwater flow in the saturated zone is simulated using a (quasi-) three-dimensional steady state solution for predicting hydraulic head and Darcy velocities in a constant thickness groundwater system subject to infiltration and recharge along the top of the aquifer and a regional hydraulic gradient defined by upstream and downstream head boundary conditions.

In addition to modeling fully three-dimensional groundwater flow and contaminant fate and transport, EPACMTP offers the option to perform quasi-3D modeling. When this option is selected, the model ignores either the flow component in the horizontal transverse (-y) direction, or the vertical (-z) direction. The appropriate 2D approximation is selected automatically in the code, based on the relative significance of plume movement in the horizontal transverse versus vertical directions. Details of this procedure are provided in the saturated zone background document (EPA, 1993a). The switching criterion that is implemented in the code will select the 2D areal solution for situations with a relatively thin saturated zone in which the contaminant plume would occupy the entire saturated thickness; conversely, the solution in which advection in the horizontal transverse direction is ignored is used in situations with a large saturated thickness, in which the effect of vertical plume movement is more important.

The saturated zone transport module describes the advective-dispersive transport of dissolved contaminants in a three-dimensional, constant thickness aquifer. The initial boundary is zero, and the lower aquifer boundary is taken to be impermeable. No-flux conditions are set for the upstream aquifer boundary. Contaminants enter the saturated zone through a patch source of either constant concentration or constant mass flux on the upper aquifer boundary, representing the area directly underneath the waste site at the soil surface. The source may be of a finite or infinite duration. Recharge of contaminant-free infiltration water occurs along the upper aquifer boundary outside the patch source. Transport mechanisms considered are advection, longitudinal, vertical and transverse hydrodynamic dispersion, linear or nonlinear equilibrium adsorption, first-order decay and daughter product formation. As in the unsaturated zone, the saturated zone transport module can simulate multi-species transport involving chained decay reactions. The saturated zone transport module of EPACMTP can perform either a fully three-dimensional transport simulation, or provide a quasi-3D approximation. The latter ignores

advection in either the horizontal transverse (-y) direction, on the vertical (-z) direction, consistent with the quasi-3D flow solution. In the course of a Monte Carlo simulation, the appropriate 2D approximations are selected automatically for each individual Monte Carlo iteration, thus yielding an overall quasi-3D simulation.

The saturated zone and transport module is based on the following assumptions:

- The aquifer is uniform and initially contaminant-free.
- The flow field is at steady state; seasonal fluctuations in groundwater flow are neglected.
- The saturated thickness of the aquifer remains constant; mounding is represented by the head distribution along the top boundary of the modeled saturated zone system.
- Flow is isothermal and governed by Darcy's Law.
- The chemical is dilute and present in the solution or aquifer solid phase only.
- Adsorption onto the solid phase is described by a linear or nonlinear equilibrium isotherm.
- Chemical and/or biochemical transformation of the contaminant can be described as a first-order process.

2.2.3 Model capabilities and limitations

EPACMTP is based on a number of simplifying assumptions which make the code easier to use and ensure its computational efficiency. These assumptions, however, may cause application of the model to be inappropriate in certain situations.

The main assumptions embedded in the fate and transport model are summarized in the previous sections and are discussed in more detail here. The user should verify that the assumptions are reasonable for a given application.

Uniform Porous Soil and Aquifer Medium. EPACMTP assumes that the soil and aquifer behave as uniform porous media and that flow and transport are described by Darcy's law and the advection-dispersion equation, respectively. The model does not account for the presence of cracks, macro-pores, and fractures. Where these features are present, EPACMTP may underpredict the rate of contaminant movement.

Single Phase Flow and Transport. The model assumes that the water phase is the only mobile phase and disregards interphase transfer processes other than reversible adsorption onto the solid phase. For example, the model does not account for volatilization in the unsaturated zone, which will tend to give conservative predictions for volatile chemicals. The model also does not account for the presence of a second liquid phase (e.g., oil). When a mobile oil phase is present, the movement of hydrophobic chemicals may be underpredicted by the model, since significant migration may occur in the oil phase rather than in the water phase.

Equilibrium Adsorption. The model assumes that adsorption of contaminants onto the soil or aquifer solid phase occurs instantaneously, or at least rapidly relative to the rate of contaminant movement. In addition, the adsorption process is taken to be entirely reversible.

Geochemistry. The EPACMTP model does not account for complex geochemical processes, such as ion exchange, precipitation and complexation, which may affect the migration of chemicals in the subsurface environment. EPACMTP can only approximate such processes as an effective equilibrium retardation process. The effect of geochemical interactions may be especially important in the fate and transport analyses of metals. Enhancement of the model for handling a wide variety of geochemical conditions is currently underway.

First-Order Decay. It is assumed that the rate of contaminant loss due to decay reactions is proportional to the dissolved contaminant concentration. The model is based on one overall decay constant and does not explicitly account for multiple degradation processes, such as oxidation, hydrolysis, and biodegradation. When multiple decay processes do occur, the user

must determine the overall, effective decay rate. In order to increase flexibility of the model, the user may instruct the model to determine the overall decay coefficient from chemical specific hydrolysis constants plus soil and aquifer temperature and pH.

Prescribed Decay Reaction Stoichiometry. For scenarios involving chained decay reactions, EPACMTP assumes that the reaction stoichiometry is always prescribed, and the speciation factors are specified by the user as constants (see *EPACMTP Background Document*, EPA, 1993a). In reality, these coefficients may change as functions of aquifer conditions (temperature, pH, etc.) and/or concentration levels of other chemical components.

Uniform Soil. EPACMTP assumes that the unsaturated zone profile is homogeneous. The model does not account for the presence of cracks and/or macropores in the soil, nor does it account for lateral soil variability. The latter condition may significantly affect the average transport behavior when the waste source covers a large area.

Steady-State Flow in the Unsaturated-Zone. Flow in the unsaturated zone is always treated as steady state, with the flow rate determined by the long term, average infiltration rate through a disposal unit, or by the average depth of ponding in a surface impoundment. Considering the time scale of most practical problems, assuming steady-state flow conditions in the unsaturated zone is reasonable.

Groundwater Mounding. The saturated zone module of EPACMTP is designed to simulate flow and transport in an unconfined aquifer. Groundwater mounding beneath the source is represented only by increased head values on top of the aquifer. The saturated thickness of the aquifer remains constant in the model, and therefore the model treats the aquifer as a confined system. This approach is reasonable as long as the mound height is small relative to the saturated thickness of the aquifer and the thickness of the unsaturated zone. For composite modeling, the effect of mounding is partly accounted for in the unsaturated zone module, since the soil is allowed to become saturated. The aquifer porous material is assumed to be uniform,

although the model does account for anisotropy in the hydraulic conductivity. The lower aquifer boundary is assumed to be impermeable.

Flow in the Saturated Zone. Flow in the saturated zone is taken to be at steady state. The concept is that of regional flow in the horizontal longitudinal direction, with vertical disturbance due to recharge and infiltration from the overlying unsaturated zone and waste site (source area). EPACMTP accounts for variable recharge rates underneath and outside the source area. It is, however, assumed that the saturated zone has a constant thickness, which may cause inaccuracies in the predicted groundwater flow and contaminant transport in cases where the infiltration rate from the waste disposal facility is high.

Transport in the Saturated Zone. Contaminant transport in the saturated zone is by advection and dispersion. The aquifer is assumed to be initially contaminant free and contaminants enter the aquifer only from the unsaturated zone immediately underneath the waste site, which is modeled as a rectangular horizontal plane source. EPACMTP can simulate both steady state and transient transport in the saturated zone. In the former case, the contaminant mass flux entering at the water table must be constant with time. In the latter case, the flux at the water table can be constant or vary as a function of time. The transport module accounts for equilibrium adsorption and decay reactions, both of which are modeled in the same manner as in the unsaturated zone. The adsorption and decay coefficients are assumed to be uniform throughout saturated zone.

2.3 Monte Carlo Module

EPACMTP was designed to perform simulations on a nationwide basis, and to account for variations of model input parameters reflecting variations in site and hydrogeological conditions. The fate and transport model is therefore linked to a Monte Carlo driver which generates model input parameter values from the probability distribution of each parameter. The Monte Carlo modeling procedure is described in more detail in this section.

The Monte Carlo method requires that for each input parameter, except constant parameters, a probability distribution is provided. The method involves the repeated generation of pseudo-random values of the uncertain input variable(s) (drawn from the known distribution and within the range of any imposed bounds) and the application of the model using these values to generate a series of model responses (receptor well concentration). These responses are then statistically analyzed to yield the cumulative probability distribution of the model output. Thus, the various steps involved in the application of the Monte Carlo simulation technique are:

- (1) Selection of representative cumulative probability distribution functions for the relevant input variables.
- (2) Generation of a pseudo-random number from the distributions selected in (1). These values represent a possible set of values (a realization) for the input variables.
- (3) Application of the fate and transport simulation modules to compute the output(s), i.e., downstream well concentration.
- (4) Repeated application of steps (2) and (3) for a specified number of iterations.
- (5) Presentation of the series of output (random) values generated in step (3).
- (6) Analysis of the Monte Carlo output to derive regulatory DAF values.

The Monte Carlo module designed for implementation with the EPACMTP composite model performs steps 2-5 above. This process is shown conceptually in Figure 2. Step 6 is performed as a post-processing step. This last step simply involves converting the normalized receptor well concentrations to DAF values, and ranking then for high to low values. Each Monte Carlo iteration yields one DAF value for the constituent of concern (plus one DAF value for each of the transformation products, if the constituent is a degrader). Since each Monte Carlo iteration has equal probability, ordering the DAF values from high to low, directly yields their cumulative probability distribution (CDF). If appropriate, CDF curves representing different regional distributions may be combined into a single CDF curve, which is a weighted average of the regional curves.

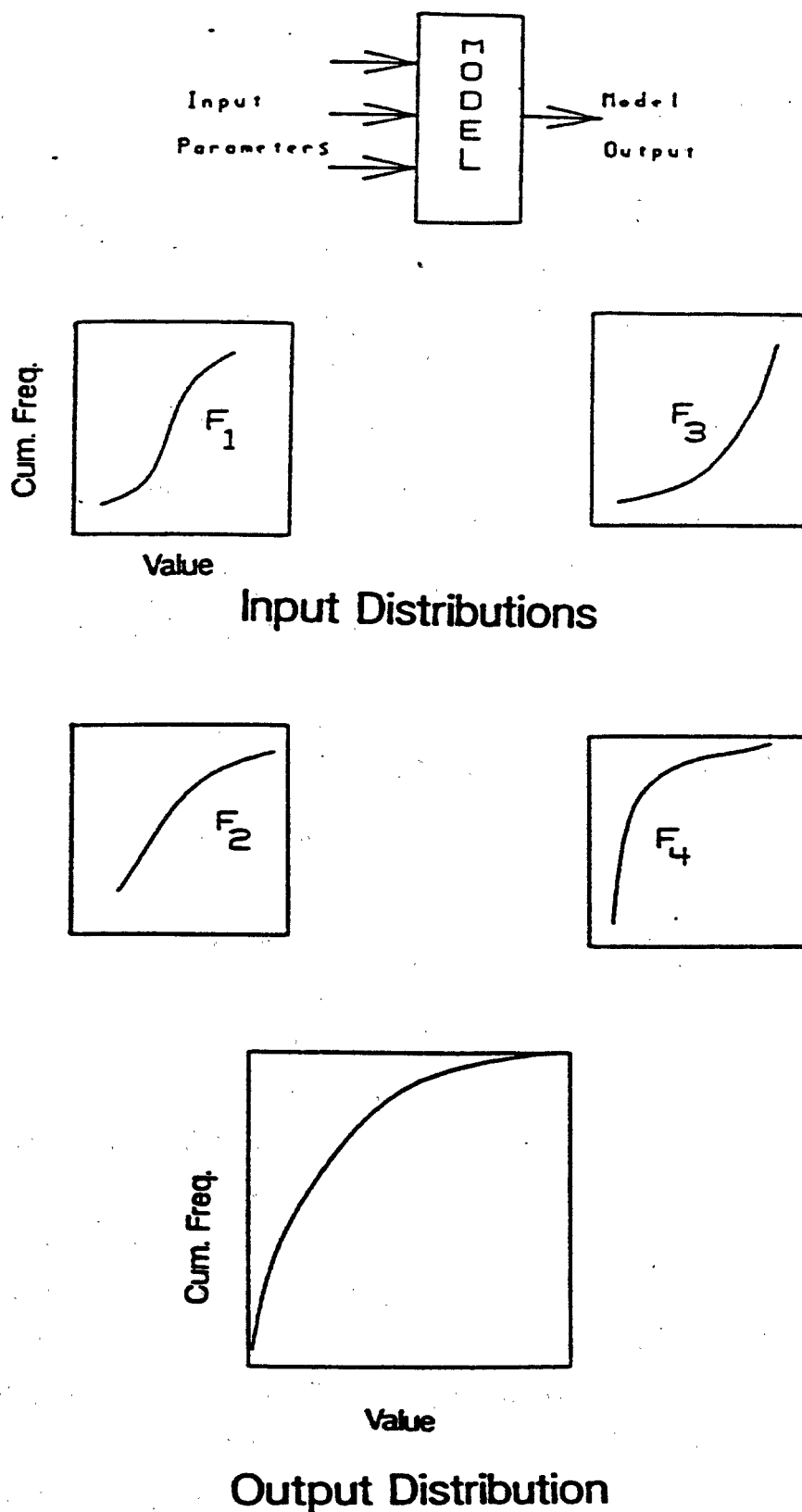


Figure 2 Conceptual Monte Carlo framework for deriving probability distribution of model output from probability distributions of input parameters.

A simplified flow chart that illustrated the linking of the Monte Carlo module to the simulation modules of the EPACMTP composite model is presented in Figure 3. The modeling input data is read first, and subsequently the desired random numbers are generated. The generated random and/or derived parameter values are then assigned to the model variables. Following this, the contaminant transport fate and transport simulation is performed. The result is given in terms of the predicted contaminant concentration(s) in a down-stream receptor well. The generation of random parameter values and fate and transport simulation is repeated as many times as desired to determine the probability distribution of down-stream well concentrations.

2.3.1 Capabilities and Limitations of Monte Carlo Module

The Monte Carlo module in EPACMTP is implemented as a flexible module that can accommodate a wide variety of input distributions. These include: constant, normal, log-normal, exponential, uniform, \log_{10} uniform, , Johnson SB, empirical, or derived. In addition, specific upper and/or lower bounds can be provided for each parameter. The empirical distribution is used when the data does not fit any of the other probability distributions. When the empirical distribution is used, the probability distribution is specified in tabular form as a list of parameter values versus cumulative probability, from zero to one.

It is important to realize that the Monte Carlo method accounts for parameter variability and uncertainty; it does, however, not provide a way to account or compensate for process uncertainty. If the actual flow and transport processes that may occur at different sites, are different from those simulated in the fate and transport module, the result of a Monte Carlo analysis may not accurately reflect the actual variation in groundwater concentrations.

EPACMTP does not directly account for potential statistical dependencies, i.e., correlations between parameters. The probability distributions of individual parameters are considered to be statistically independent. At the same time, EPACMTP does incorporate a number of safeguards against generating impossible combinations of model parameters. Lower and upper bounds on the parameters prevent unrealistically low or high values from being generated at all.

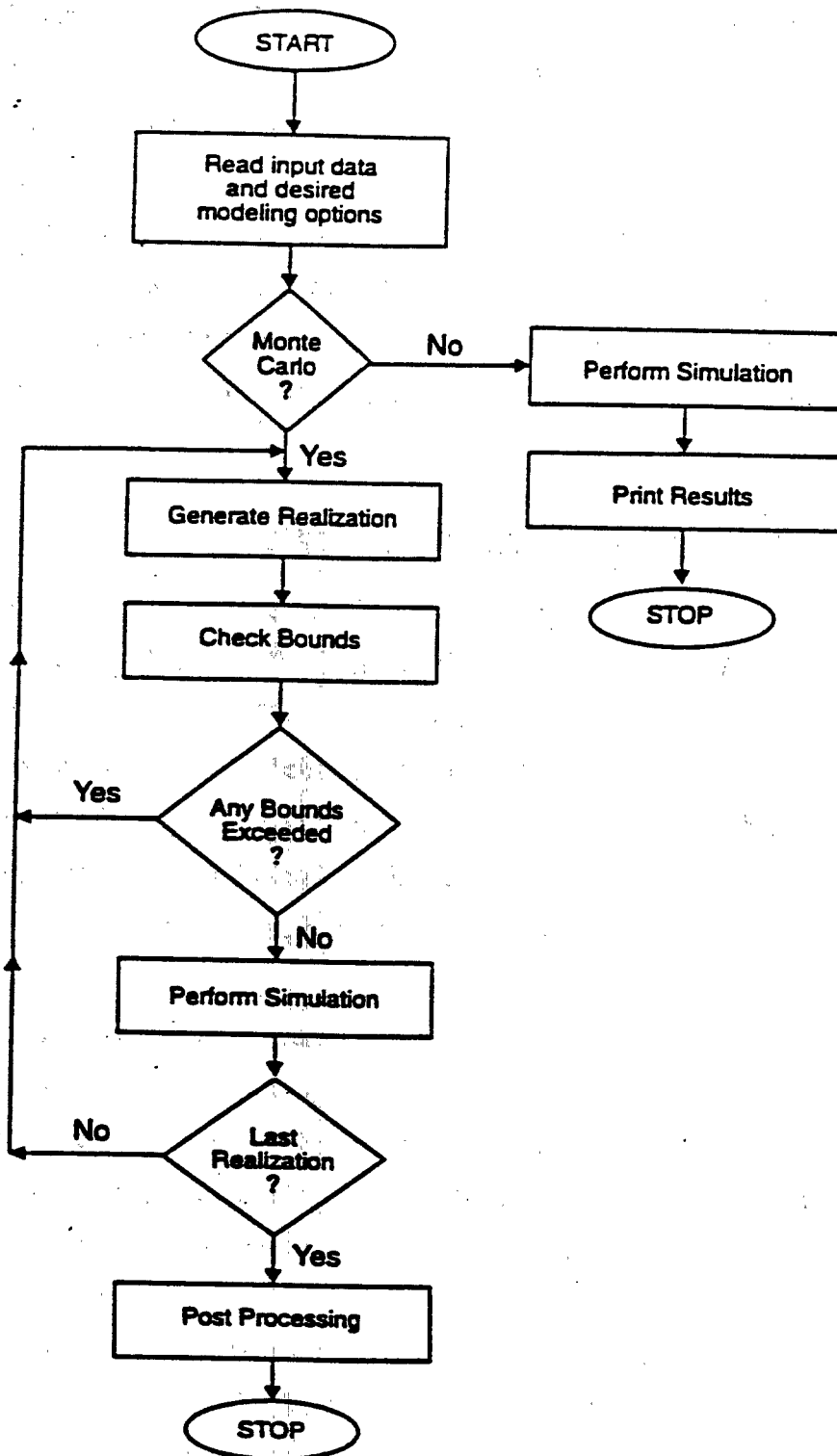


Figure 3 Flow chart of EPACMTP for Monte Carlo simulation.

In the case of model parameters that have a direct physical dependence on other parameters, these parameters can be specified as derived parameters. For instance, the ambient groundwater flow rate is determined by the regional hydraulic gradient and the aquifer hydraulic conductivity. In the Monte Carlo analyses, the ambient groundwater flow rate is therefore calculated as the product of conductivity and gradient, rather than generated independently. A detailed discussion of the derived parameters used in the model is provided in the *EPACMTP User's Guide* (EPA, 1994).

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3.0 MODELING PROCEDURE

This section documents the modeling procedure followed in determining the groundwater pathway DAF values for the Soil Screening Levels. Section 3.1 describes the overall approach for the modeling analysis; section 3.2 describes the model options used and summarizes the input parameter values.

3.1 Modeling Approach

The overall modeling approach consisted of two stages. First, a sensitivity analysis was performed to determine the optimal number of Monte Carlo repetitions required to achieve a stable and converged result, and to determine which site-related parameters have the greatest impact on the DAFs. Secondly, Monte Carlo analyses were performed to determine DAF values as a function of the size of the source area, for various scenarios of receptor well placement.

3.1.1 Determination of Monte Carlo Repetition Number and Sensitivity Analysis

The criterion for determining the optimal number of Monte Carlo repetitions was set to a change in DAF value of no more than 5 percent when the number of repetitions is varied. A Monte Carlo simulation comprising 20,000 repetitions was first made. The results from this simulation were analyzed by calculating the 85th percentile DAF value obtained by sampling model output sequences of different length, from 2,000 to the full 20,000 repetitions. The modeling scenario considered in this analysis was the same as that in the base case scenario discussed in the next section, with the size of the source area set to 10,000 m².

The sensitivity analysis on site-related model parameters was performed by fixing one parameter at a time, while remaining model parameters were varied according to their default, nationwide probability distributions as discussed in the EPACMTP User's Guide (EPA, 1993b).

For each parameter, the low, medium, and high values were selected, corresponding to the 15th, 50th, and 85th percentile, respectively, of that parameter's probability distribution. As a result, the sensitivity analysis reflects, in part, the width of each parameter's probability distribution. Parameters with a narrow range of variation will tend to be among the less sensitive parameters, and vice versa for parameters that have a wide range of variation. By conducting the sensitivity analysis as a series of Monte Carlo simulations, any parameter interactions on the model output are automatically accounted for. Each of the Monte Carlo simulations yields a probability distribution of predicted receptor well concentrations. Evaluating the distributions obtained with different fixed values of the same parameter provides a measure of the overall sensitivity and impact of that parameter. In each case the model was run for 2000 Monte Carlo iterations. Steady-state conditions (continuous source) were simulated in all cases.

In a complete Monte Carlo analysis, over 20 different model parameters are involved. These parameters may be divided into two broad categories. The first includes parameters that are independent of contaminant-specific chemical properties, e.g., depth to water table, aquifer thickness, receptor well distance, etc. The second category encompasses those parameters that are related to contaminant-specific sorption and biochemical transformation characteristics. This category includes the organic carbon partition coefficient, but also parameters such as aquifer pH, temperature and fraction organic carbon. The sensitivity of the model to the first category of parameters has been examined, by considering a non-degrading, non-sorbing contaminant. Under these conditions, any parameters in the second category will have zero sensitivity. In addition, all unsaturated zone parameters can be left out of the analysis, since the predicted steady state contaminant concentration at the water table will always be the same as that entering the unsaturated zone. The only exception to this is the soil type parameter. In the nationwide Monte Carlo modeling approach, different soil types are distinguished. Each of the three different soil types (sandy loam, silt loam or silty clay loam) has a different distribution of infiltration rate, with the sandy loam soil type having the highest infiltration rates, silty clay loam having the lowest, and silty loam having intermediate rates. The effect of the soil type parameter is thus intermixed with that of infiltration rate. Table 1 lists the input 'low', 'medium' and 'high' values for all the parameters examined.

Table 1 Parameter input values for model sensitivity analysis.

Parameter	Low	Median	High
<u>Source Parameters</u>			
Source Area (m ²)	4.8×10^4	2.8×10^5	1.1×10^6
Infiltration Rate (m/yr)	6.0×10^{-4}	6.4×10^{-3}	1.7×10^{-1}
Recharge Rate (m/yr)	6.0×10^{-4}	8.0×10^{-3}	1.5×10^{-1}
<u>Saturated Zone Parameters</u>			
Saturated Thickness (m)	15.55	60.8	159.3
Hydraulic conductivity (m/yr)	1.9×10^3	1.5×10^4	5.5×10^4
Regional gradient	4.3×10^{-3}	1.8×10^{-2}	5.0×10^{-2}
Ambient groundwater velocity (m/yr)	53.2	404.0	2883.0
Porosity	0.374	0.415	0.455
Longitudinal Dispersivity (m)	4.2	12.7	98.5
Transverse Dispersivity (m)	0.53	1.59	12.31
Vertical Dispersivity (m)	0.026	0.079	0.62

3.1.2 Analysis of DAF Values for Different Source Areas

Following completion of the sensitivity analysis discussed above, an analysis was performed of the variation of DAF values with size of the contaminated area. The sensitivity analysis, results of which are presented in Section 4.1, showed that the size of the contaminated source area is one of the most sensitive parameters in the model. For the purpose of deriving DAF values for the groundwater pathway in determining soil screening levels, it would therefore be appropriate to correlate the DAF value to the size of the contaminated area.

The EPACMTP modeling analysis was designed to determine the size of the contaminated area that would result in DAF values of 10 and 100 at the upper 85th, 90th, and 95th percentile of probability, respectively. Since it is not possible to directly determine the source area that results in a specific DAF value, the model was executed for a range of different source areas, using a different but fixed source area value in each Monte Carlo simulation. The 85th, 90th, and 95th percentile DAF values were then plotted against source area, in order to determine the value of source area corresponding to a specific DAF value.

3.1.2.1 *Model Options and Input Parameters*

Table 2 summarizes the EPACMTP model options used in performing the simulations. Model input parameters used are summarized in Table 3. The selected options and input parameter distributions and values are consistent with those used in the default nationwide modeling, and are discussed individually in the *EPACMTP User's Guide* (EPA, 1994). Exceptions to this default modeling scenario are discussed below.

Source Area

In the default, nationwide modeling scenario, the waste site area, or source area, is treated as a Monte Carlo variable, with a distribution of values equal to that of the type of waste unit, e.g. landfills, considered. In the present modeling analyses, the source area was set to a different but constant value in each simulation run.

Table 2 Summary of EPACMTP modeling options.

OPTION	Value Selected
Simulation Type	Monte Carlo
Number of Repetitions	15,000
Nationwide Aggregation	Yes
Source Type	Continuous
Unsat. Zone Present	Yes
Sat. Zone Model	Quasi-3D
Contaminant Degradation	No
Contaminant Sorption	No

Table 3 Summary of EPACMTP input parameters.

Parameter	Value or Distribution Type	Comment
<u>Source-Specific</u>		
Area	Constant	Varied in each run
Infiltration Rate	Soil-type dependent	default
Recharge Rate	Soil-type dependent	default
Leachate Concentration	= 1.0	default
<u>Chemical-Specific</u>		
Hydrolysis Rate Constants	= 0.0	Contaminant does not degrade
Organic Carbon Partition Coeff.	= 0.0	Contaminant does not sorb
<u>Unsaturated Zone Specific</u>		
Depth to Water Table	Empirical	default
Dispersivity	Soil-depth dependent	default
Soil Hydraulic Properties	Soil-type dependent	default
Soil Chemical Properties	Soil-type dependent	default
<u>Saturated Zone Specific</u>		
Sat. Zone Thickness	Exponential	default
Hydraulic Conductivity	Derived from Part. Diam.	default
Hydraulic Gradient	Exponential	default
Seepage Velocity	Derived from Conductivity and Gradient	default
Particle Diameter	Empirical	default
Porosity	Derived from Part. Diam	default
Bulk Density	Derived from Porosity	default
Longitudinal Dispersivity	Distance-dependent	default
Transverse Dispersivity	Derived from Long. Dispersivity	default
Vertical Dispersivity	Derived from Long. Dispersivity	default
Receptor Well x-coordinate	= 25 feet	Set to fixed value
Receptor Well y-coordinate	Within plume	default
Receptor Well z-coordinate	Empirical	default

Note: 'Default' represents default nationwide Monte Carlo scenario as presented in *EPACMTP User's Guide* (EPA, 1994).

Receptor Well Location

In the default nationwide modeling scenario, the position of the nearest downgradient receptor well in the saturated zone is treated as a Monte Carlo variable. The position of the well is defined by its x-, y-, and z-coordinates. The x-coordinate represents the distance along the ambient groundwater flow direction from the downgradient edge of the contaminated area. The y-coordinate represents the horizontal transverse distance of the well from the plume centerline. The x- and y-coordinate in turn can be defined in terms of an overall downgradient distance, and an angle off-center (EPA, 1994). The z-coordinate represents the depth of the well intake point below the water table. This is illustrated schematically in Figure 4, which shows the receptor well location in both plan view and cross-sectional view.

In the default nationwide modeling scenario, the x- and z-coordinates of the well are determined from Agency surveys on the distance of residential wells from municipal landfills, and data on the depth of residential drinking water wells, respectively. The y-coordinate value is determined so that the well location falls within the approximate areal extent of the contaminant plume (see Figure 4).

For the present modeling analysis, a number of different receptor well placement scenarios were considered. These scenarios are summarized in Table 4.

The base case scenario (scenario 1) involved setting the x-distance of the receptor well to 25 feet from the edge of the source area. Nationwide default options were used for the receptor well y- and z-coordinates. The y-coordinate of the well was assigned a uniform probability distribution within the boundary of the plume. The depth of the well intake point (z-coordinate) was assumed to vary within upper and lower bounds of 15 and 300 feet below the water table, reflecting a national sample distribution of depths of residential drinking water wells (EPA, 1994).

In addition to this base case scenario, a number of other well placement scenarios were investigated also. These are numbered in Table 4 as scenarios 2 through 6. Scenario 2

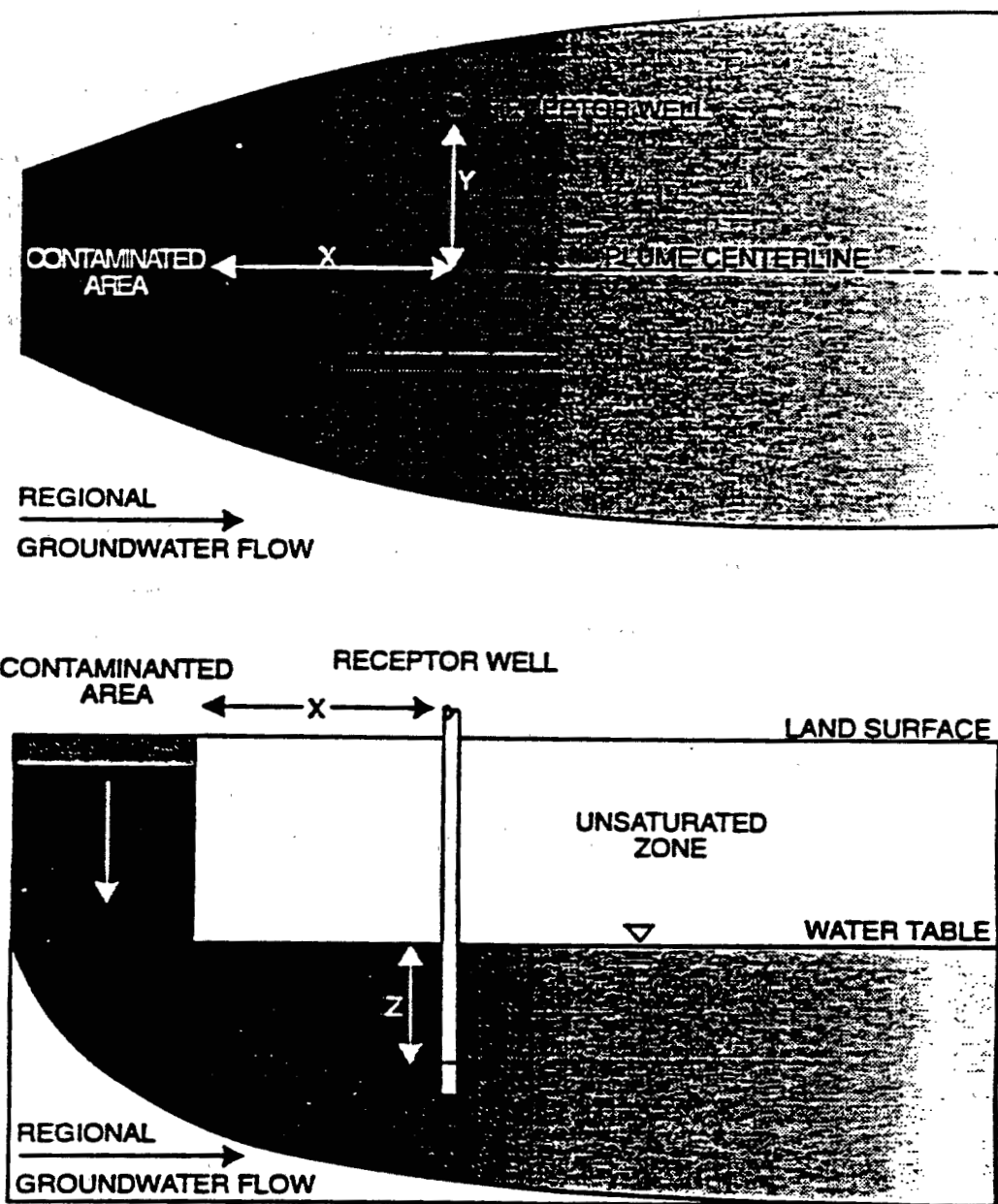


Figure 4 Plan view and cross-section view showing location of receptor well.

Table 4 Receptor well location scenarios.

Scenario	Xwell	Ywell	Zwell
1 (Base Case)	25 ft from edge of source area	Monte Carlo within plume	Nationwide Distribution
2	Nationwide Distribution	Monte Carlo within plume	Nationwide Distribution
3	0 ft from edge of source area	Monte Carlo within half-width of source area	Nationwide Distribution
4	25 ft from edge of source area	Monte Carlo within half-width of source area	Nationwide Distribution
5	100 ft from edge of source area	Monte Carlo within half-width of source area	Nationwide Distribution
6	25 ft from edge of source area	Width of source area + 25 ft	25 ft below water table

Xwell = Downgradient distance of receptor well from edge of source area.

Ywell = Horizontal transverse distance from plume centerline.

Zwell = Depth of well intake point below water table.

corresponds to the default, nationwide Monte Carlo modeling scenario in which the x, y, and z locations of the well are all variable. In scenarios 3, 4 and 5, the distance between the receptor well and the source area is varied from zero to 100 feet. In these scenarios, the y-coordinate of the well was constrained to the central portion of the plume. In scenario number 6, the x-, y-, and z-coordinates of the receptor well were all set to constant values. These additional scenarios were included in the analysis in order to assess the sensitivity of the model results to the location of the receptor well.

Aquifer Particle Size Distribution

In the default Monte Carlo modeling scenario, the aquifer hydraulic conductivity, porosity, and bulk density are determined from the mean particle diameter. The particle diameter distribution used is based on data compiled by Shea (1974). In the present modeling analyses for fixed waste site areas, the same approach and data were used, but the distribution was shifted somewhat to assign more weight to the smallest particle diameter interval. The result is that lower values of the hydraulic conductivity values generated, and also of the ambient groundwater seepage velocities, received more emphasis. Lower ambient groundwater velocities reduce the degree of dilution of the incoming contaminant plume and therefore result in lower, i.e. more conservative, DAF values. Table 5 summarizes the distribution of particle size diameters used in both the default nationwide modeling scenario and in the present analyses.

Table 5 Distribution of aquifer particle diameter.

<u>Nationwide Default</u>		<u>Present Analyses</u>	
Particle Diameter (cm)	Cumulative Probability	Particle Diameter (cm)	Cumulative Probability
3.9 10 ⁻⁴	0.000	4.0 10 ⁻⁴	0.100
7.8 10 ⁻⁴	0.038	8.0 10 ⁻⁴	0.150
1.6 10 ⁻³	0.104	1.6 10 ⁻³	0.200
3.1 10 ⁻³	0.171	3.1 10 ⁻³	0.270
6.3 10 ⁻³	0.262	6.3 10 ⁻³	0.330
1.25 10 ⁻²	0.371	1.25 10 ⁻²	0.440
2.5 10 ⁻²	0.560	2.5 10 ⁻²	0.590
5.0 10 ⁻²	0.792	5.0 10 ⁻²	0.790
1.0 10 ⁻¹	0.904	1.0 10 ⁻¹	0.880
2.0 10 ⁻¹	0.944	2.0 10 ⁻¹	0.910
4.0 10 ⁻¹	0.946	4.0 10 ⁻¹	0.940
8.0 10 ⁻¹	1.000	7.5 10 ⁻¹	1.000

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4.0 RESULTS

This section presents the results of the modeling analyses performed. The analysis of the convergence of the Monte Carlo simulation is presented first, followed by the parameter sensitivity analysis, and thirdly the analysis of DAF values as a function of source area for various well placement scenarios.

4.1 Convergence of Monte Carlo Simulation

Table 6 summarizes the results of this convergence analysis. It shows the variation of the 85th percentile DAF value with the number of Monte Carlo repetitions, from 2,000 to 20,000. The variations in DAF values are shown both as absolute and relative differences. The table shows that for this example, the DAF generally increases with the number of Monte Carlo repetitions. It should be kept in mind that the results from different repetition numbers as presented in the table, are not independent of one another. For instance, the first 2000 repetitions are also incorporated in the 5000 repetition results, which in turn is in the 10,000 repetition result, etc. The rightmost column of Table 6 shows the percentage difference in DAF value between different repetition numbers. At repetition numbers of 14,000 or less, the percentage difference varies in a somewhat irregular manner. However, for repetition numbers of 15,000 or greater, the DAF remained relatively constant, with incremental changes of DAF remaining at 1% or less. Based upon these results, a repetition number of 15,000 was selected for use in the subsequent runs with fixed source area.

4.2 Parameter Sensitivity Analysis

Results of the parameter sensitivity analysis are summarized in Table 7. The parameters are ranked in this table in order of relative sensitivity. Relative sensitivity is defined for this purpose as the absolute difference between the "high" and "low" DAF at the 85th percentile level, divided by the 85th percentile DAF for the "median" case.

Table 6 Variation of DAF with number of Monte Carlo repetitions.

No. of Repetitions	85-th Percentile DAF	Difference	Relative Difference (%)
2,000	347.8		
		-10.9	-3.1
5,000	336.9		
		+17.3	+5.1
10,000	354.2		
		+5.0	+1.4
11,000	359.2		
		+28.2	+7.9
12,000	387.4		
		-18.1	-4.7
13,000	369.3		
		-0.2	-0.05
14,000	369.1		
		+18.2	+4.9
15,000	387.3		
		+0.1	+0.03
16,000	387.4		
		+0.6	+0.15
17,000	388.0		
		-0.7	-0.18
18,000	387.3		
		+2.9	+0.75
19,000	390.2		
		+2.6	+0.67
20,000	392.8		

Table 7 Sensitivity of model parameters.

Parameter	85% DAF Value			Relative Sensitivity*	Rank
	Low	Median	High		
Infiltration Rate	4805.4	418.8	11.6	11.4	1
Saturated Thickness	25.3	198.5	2096.9	10.4	2
G.W. Velocity	7.6	97.7	816.3	8.3	3
Source Area	357.1	85.2	35.6	3.8	4
Hydr. Conductivity	19.8	180.4	660.1	3.5	5
Vertical Well Position	49.1	206.1	491.4	2.1	6
G.W. Gradient	32.4	168.3	383.0	2.1	7
Long. Dispersivity	182.6	104.2	78.8	1.0	8
Vert. Dispersivity	179.6	114.9	66.6	1.0	9
Porosity	41.3	49.9	79.7	0.8	10
Receptor Well Distance	163.9	117.9	84.5	0.7	11
Transv. Dispersivity	156.7	156.3	173.5	0.1	12
Receptor Well Angle	127.3	130.8	113.6	0.1	13
Ambient Recharge	108.3	100.0	114.4	0.06	14

* Relative Sensitivity = $| \text{High-Low} | / \text{Median}$

The table shows that the most sensitive parameters included the rate of infiltration, which is a function of soil type, the saturated thickness of the aquifer, the size of source area, the groundwater seepage velocity, and the vertical position of the receptor well below the water table. The least sensitive parameters included porosity, downstream distance of the receptor well in both the x- and y-directions, the horizontal transverse dispersivity, and the areal recharge rate. To interpret these results, it should be kept in mind that the rankings reflect in part the range of variation of each parameter in the data set used for the sensitivity analysis. The infiltration rate was a highly sensitive parameter since, for a given leachate concentration, it directly affects the mass flux of contaminant entering the subsurface. The size of the source area would be expected to be equally sensitive, were it not for the fact that in the sensitivity analysis, the source area had a much narrower range of variation than the infiltration rate. The "high" and "low" values of the source area, which were taken from a nationwide distribution of landfill waste units, varied by a factor of 23, while the ratio of "high" to "low" infiltration rate was almost 300.

In the simulations performed for the sensitivity analysis, no constraint was imposed on the vertical position of the well. The well was modeled as having a uniform distribution with the well intake point located anywhere between the water table and the base of the aquifer. The aquifer saturated thickness and vertical position of the well were both among the sensitive parameters, with similar effects on DAF values. Increasing either the saturated thickness, or the fractional depth of the receptor well below the water table, increases the likelihood that the receptor well will be located underneath the contaminant plume and sample uncontaminated groundwater, leading to a high DAF value. The dilution-attenuation factors were also sensitive to the groundwater velocity, and the parameters that determine the groundwater velocity, i.e., hydraulic conductivity and ambient gradient. Table 7 shows that a higher groundwater velocity results in an increase of the dilution-attenuation factor. Since a conservative contaminant was simulated under steady-state conditions, variations in travel time do not affect the DAF. The increase of DAF with increasing flow velocity reflects the greater mixing and dilution of the contaminant as it enters the saturated zone in systems with high groundwater flow rate. Porosity

also directly affects the groundwater velocity, but was not among the sensitive parameters. This is a reflection of the narrow range of variation assigned to this parameter.

The off-center angle which determines the y position of the well relative to the plume center line would be expected to have a similar effect as the well depth, but is seen to have a much smaller sensitivity. This was a result of constraining the y-location of the receptor well to be always inside the approximate areal extent of the contaminant plume. The effect is that the relative sensitivity of the off-center angle was much less than that of the vertical coordinate of the well. The low relative sensitivity of recharge rate reflects the fact that this parameter has an only indirect effect on plume concentrations.

Overall, the Monte Carlo results were not very sensitive to dispersivity and downstream distance of the receptor well. The probable explanation for these parameters is that variations of the parameters produce opposing effects which tended to cancel one another. Low dispersivity values will produce a compact plume which increases the probability that a randomly located receptor well will lie outside (underneath) the plume. Higher dispersivities will increase the chance that the well will intercept the plume. At the same time, however, mass balance considerations dictate that in this case average concentrations inside the plume will be lower than in the low dispersivity case. Similar reasoning applies to the effect of receptor well distance. If the well is located near the source, concentrations in the plume will be relatively high, but so is the chance that the well does not intercept the plume at all. At greater distances from the source, the likelihood that the well is located inside the plume is greater, but the plume will also be more diluted. In the course of a full Monte Carlo simulation these opposing effects would tend to average out. The much lower sensitivity of transverse dispersivity, α_T , compared to α_L and α_v can be contributed to the imposed constraint that the well must always be within the areal extent of the plume.

The results of the sensitivity analysis show that the site characteristic which lends itself best for a classification system for correlating sites to DAF values is the size of the contaminated (or

source) area. In the subsequent analyses, the DAF values were therefore determined as a function of the source area size. These results are presented in the following section.

4.3 DAF Values as a Function of Source Area

This section presents the DAF value as a function of source area for various well location scenarios. The results for each of the scenarios examined are presented in tabular and graphical form. Figure 5 shows the variation of the 85th, 90th, and 95th percentile DAF with source area for the base case scenario. The source area is expressed in square feet. The figure displays DAF against source area in a log-log graph. The graph shows an approximately linear relationship except that at very large values of the source area, the DAF starts to level off. Eventually the DAF approaches a value of 1.0. As expected, the curve for the 95th percentile DAF always shows the lowest DAF values, while the 85th percentile shows the highest DAFs. The DAF versus source area relationship for the other well placement scenarios are shown in Figures 6 through 10. The numerical results for each scenario are summarized in Tables A1 through A6 in the appendix.

Inspection and comparison of the results for each scenario indicate that the relationship follows the same general shape in each case, but the magnitude of DAF values at a given source area can be quite different for different well placement scenarios. In order to allow a direct comparison between the various scenarios analyzed, the DAF values obtained for a source area of 150,000 ft² (3.4 acres) are shown in Table 8 as a function of the receptor well location scenario.

Inspection of the DAF values shows that the default nationwide scenario for locating the receptor well results in the highest DAF values, as compared to the base case scenario and the other scenarios, in which the receptor well location was fixed at a relatively close distance from the waste source. In the default nationwide modeling scenario, the well location is assigned from nationwide data on both the distance from the waste source and depth of the well intake point below the water table. In the default nationwide modeling scenario, the receptor well is allowed to be located up to 1 mile from the waste source. In the base case (Scenario 1) the well is

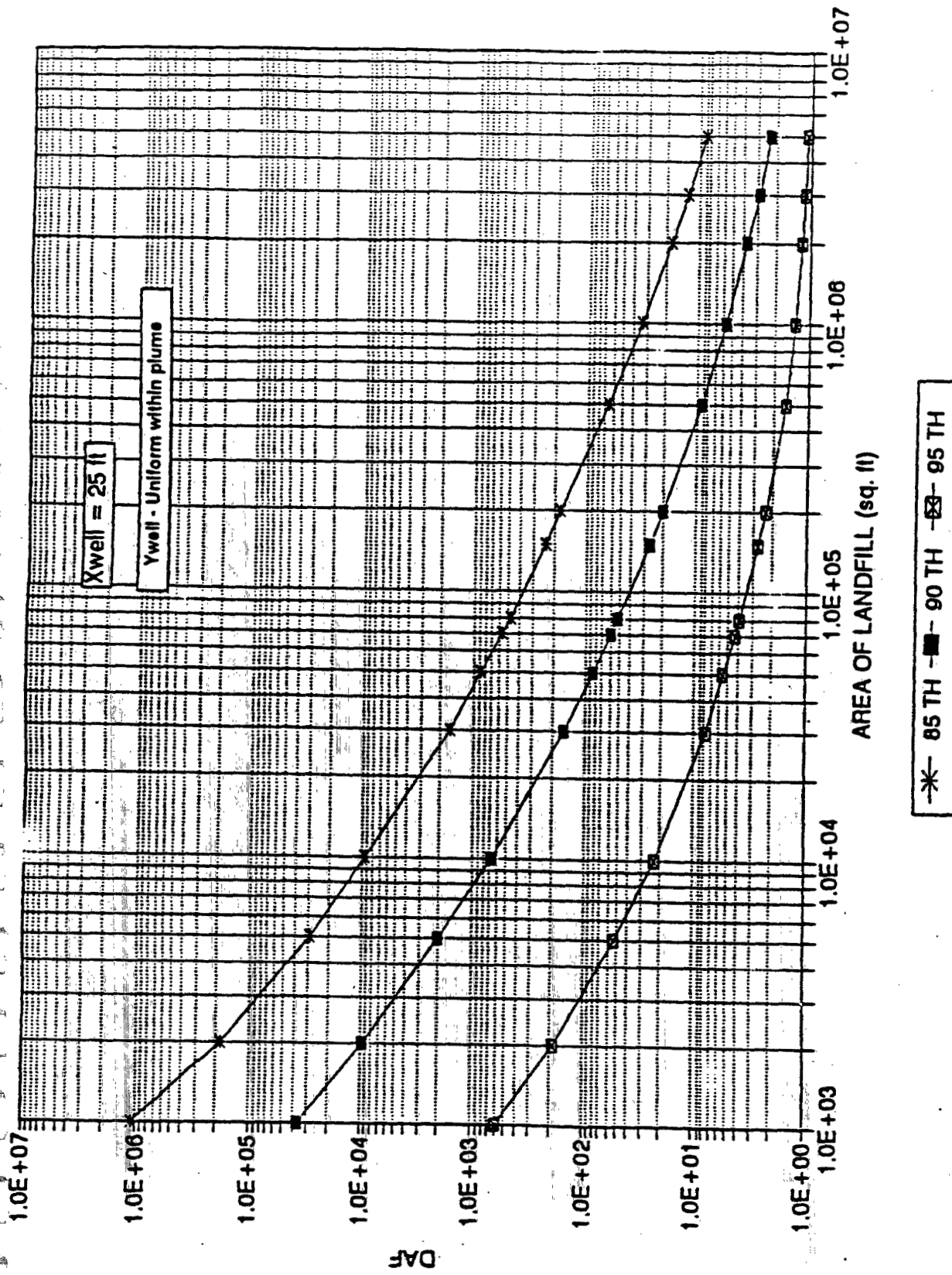
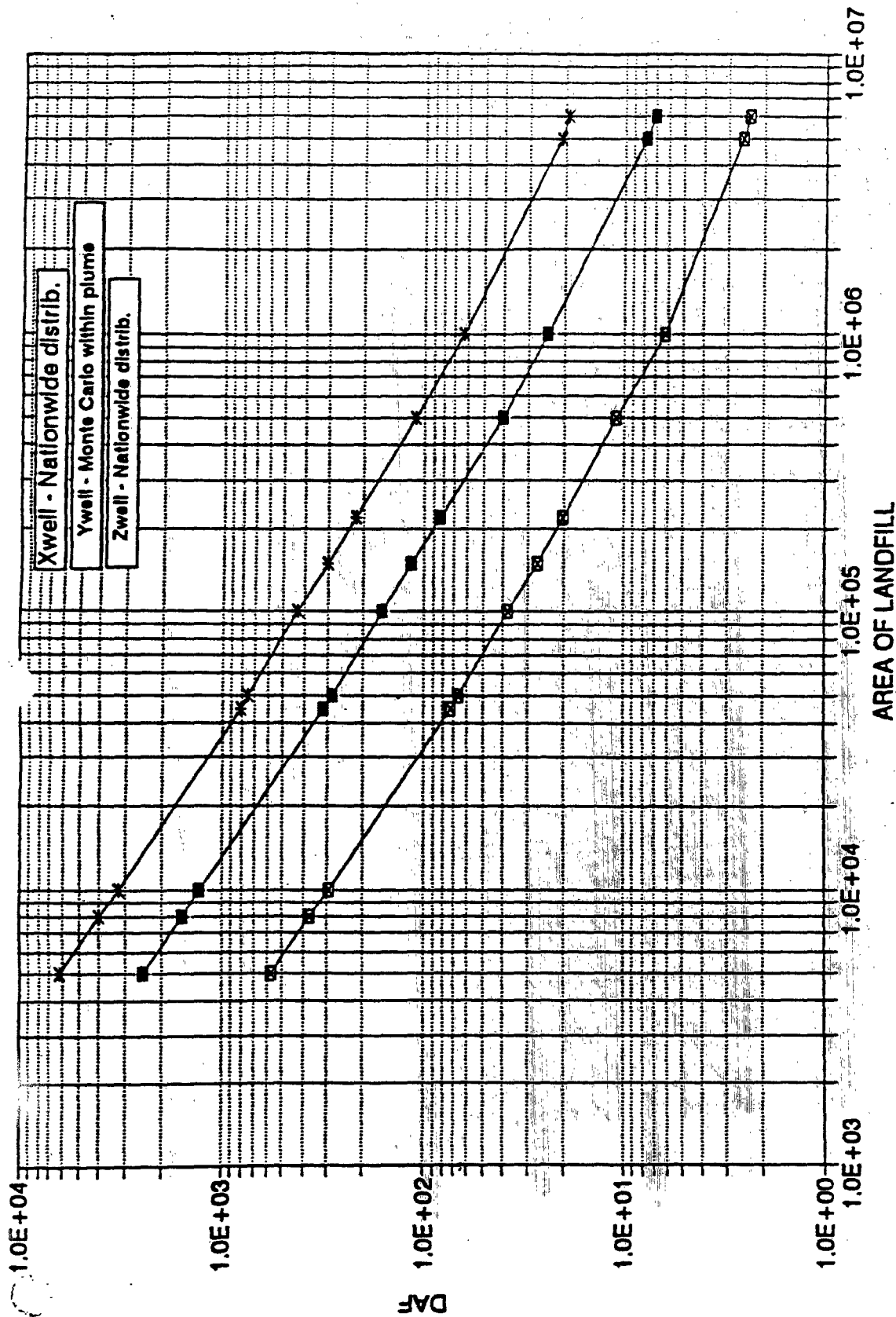


Figure 5 Variation of DAF with size of source area for the base case scenario ($x=25 \text{ ft}$, $y=\text{uniform in plume}$, $z=\text{nationwide distribution}$).



—*— 85 TH —■— 90 TH —□— 95 TH

Figure 6 Variation of DAF with size of source area for the default nationwide scenario (Scenario 2: x = nationwide distribution, y = uniform in plume, z = nationwide distribution).

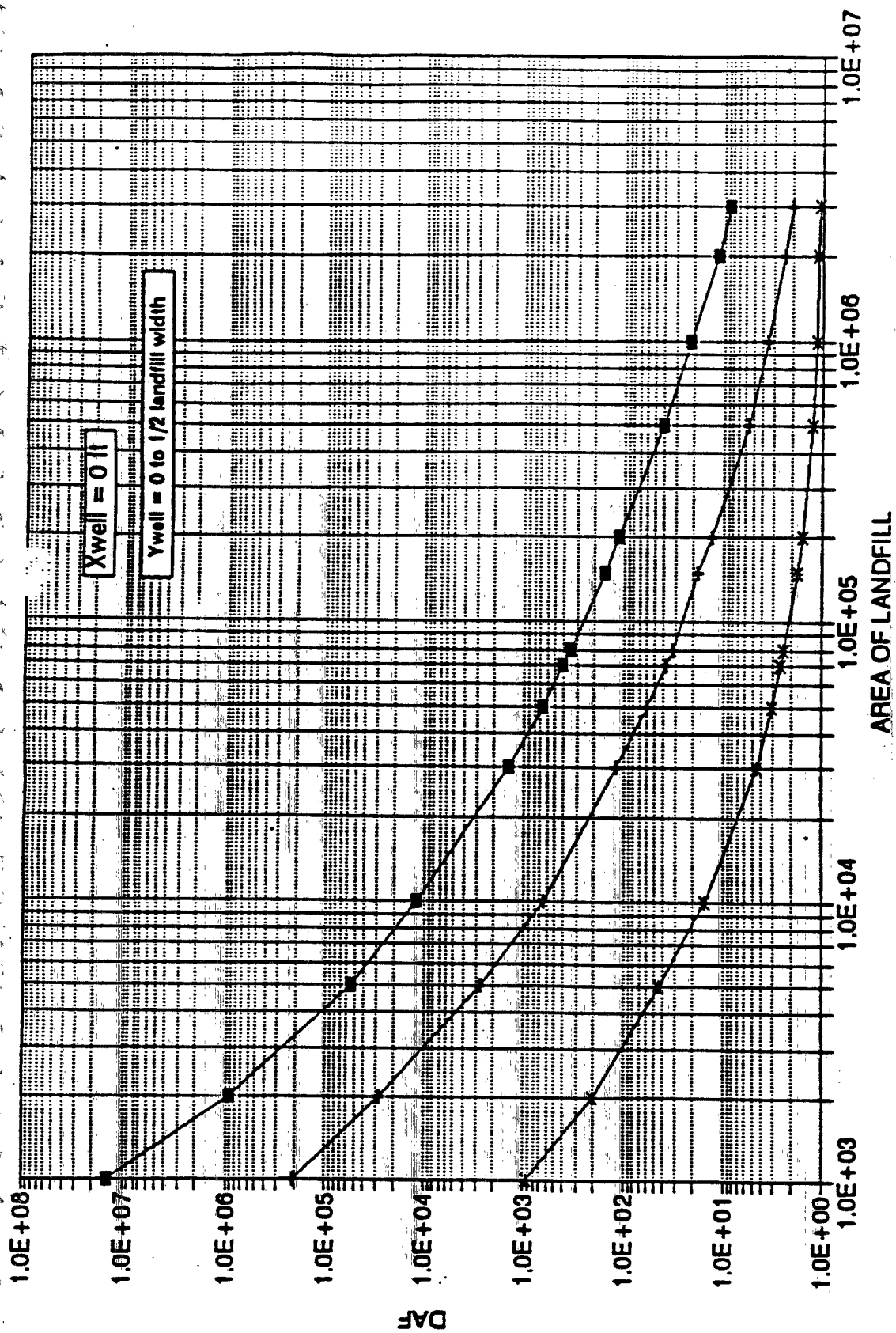


Figure 7 Variation of DAF with size of source area for Scenario 3 ($x=0$, y =uniform within half-width of source area, z =nationwide distribution).

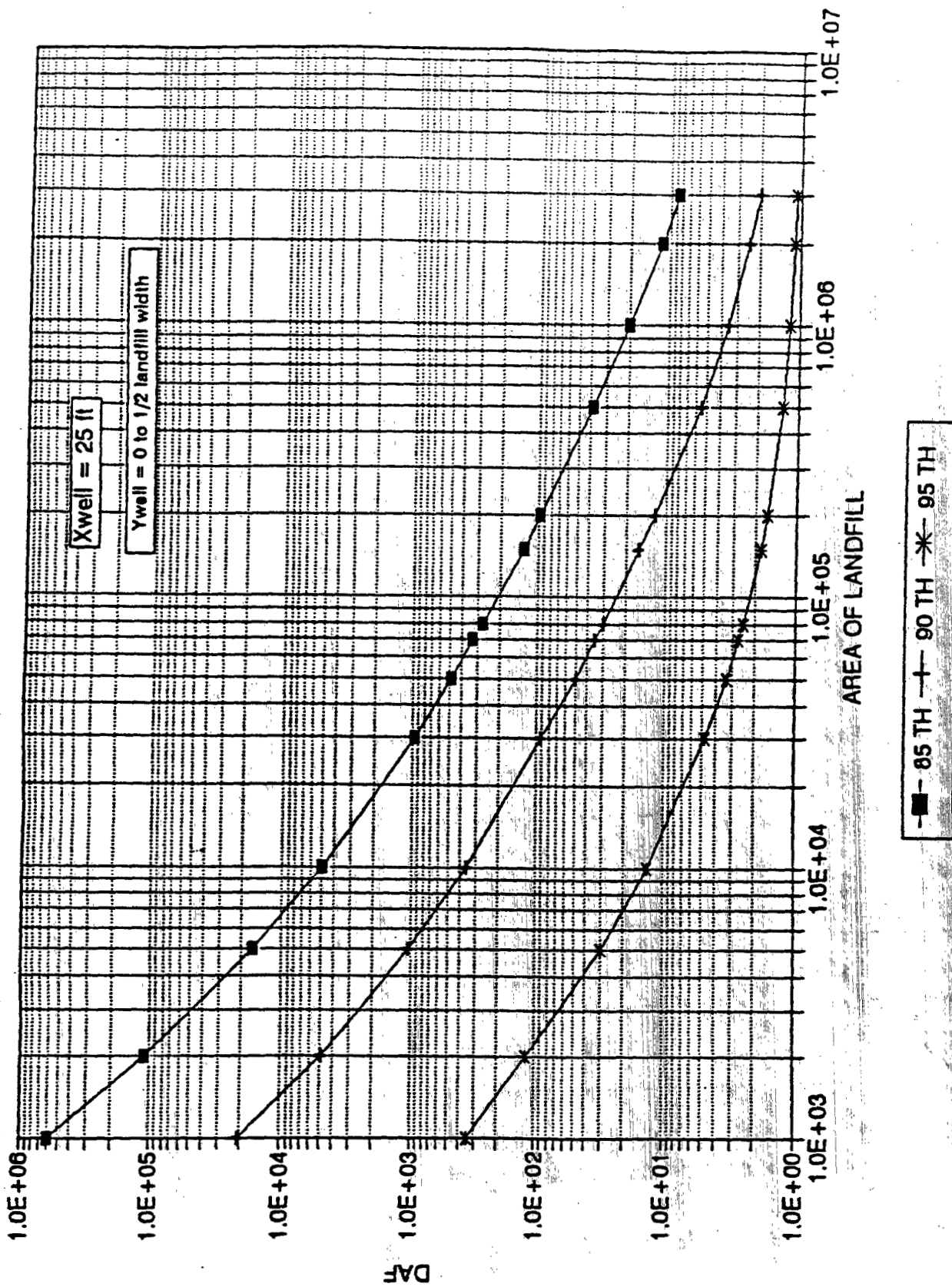


Figure 8 Variation of DAF with size of source area for Scenario 4 ($x=25$ ft, y =uniform within half-width of source area, z =nationwide distribution).

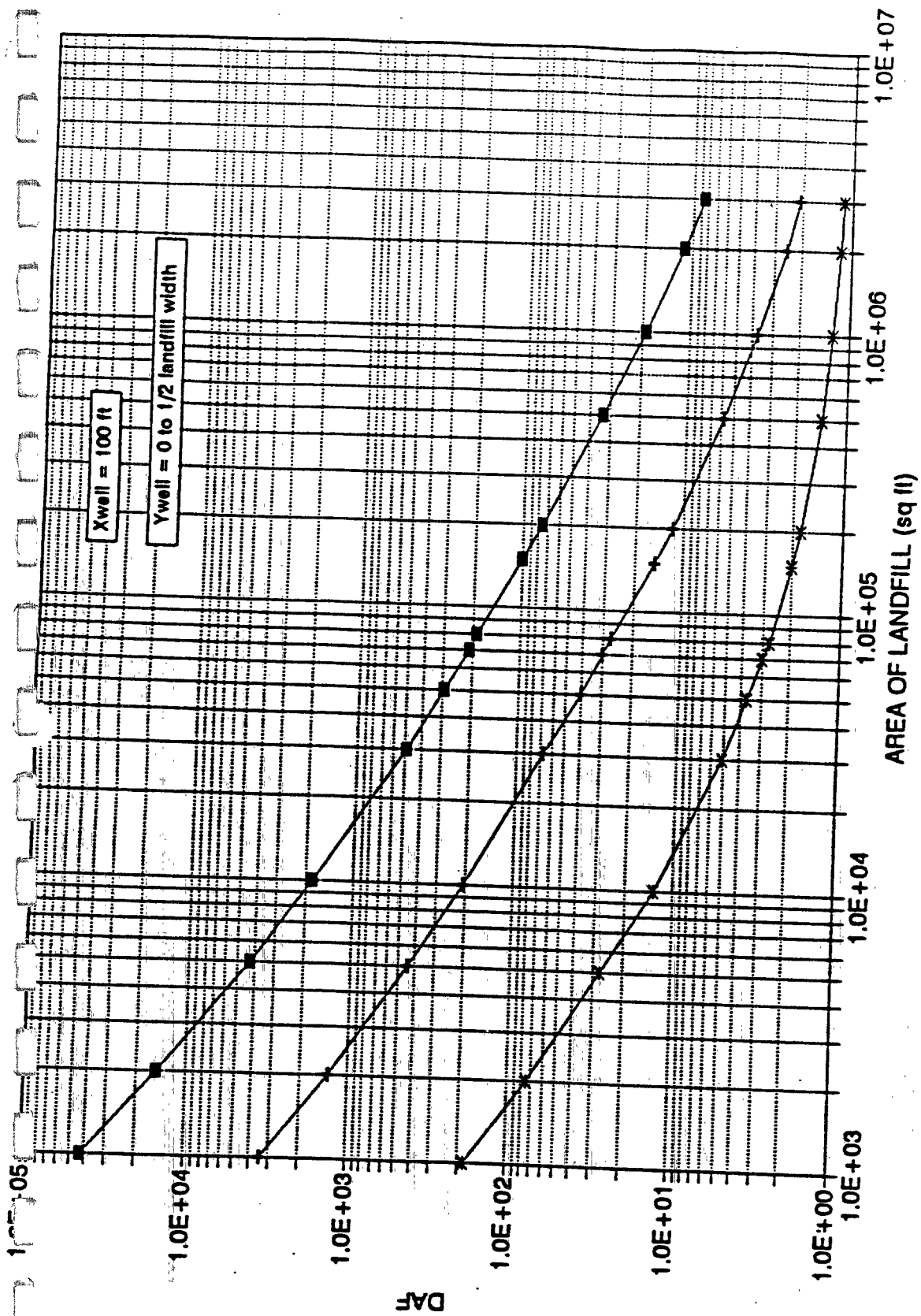
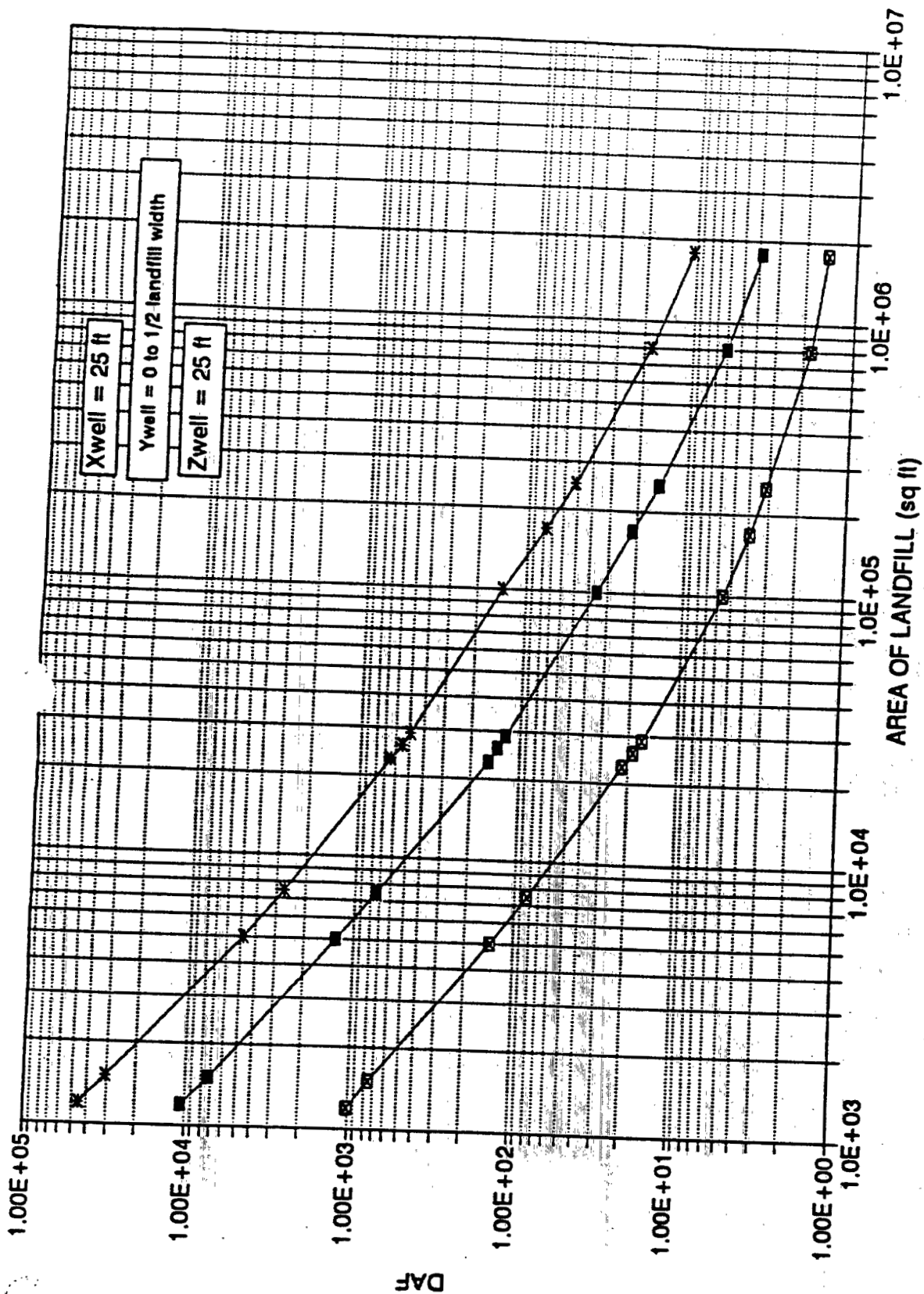


Figure 9

Variation of DAF with size of source area for Scenario 5 ($x = 100$ ft, $y =$ uniform within half-width of source area, $z =$ nationwide distribution).



* 85 TH ■ 90 TH □ 95 TH

Figure 10 Variation of DAF with size of source area for Scenario 6 ($x=25 \text{ ft}$, $y=\text{width of source area} + 25 \text{ ft}$, $z=25 \text{ ft}$).

Table 8 DAF values for waste site area of 150,000 ft².

Model Scenario	DAF Percentile		
	85	90	95
1 (base case)	237.5	26.4	2.8
2	300.1	114.7	26.8
3	158.8	17.9	1.7
4	132.1	16.6	1.8
5	98.8	15.1	2.0
6	94.7	25.3	4.4

allowed to be located anywhere within the areal extent of the contaminant plume for a fixed x-distance of 25 feet. This allows the well to be located near the fringes of the contaminant plume where concentrations are relatively low and DAF values are correspondingly high. In contrast, in Scenarios 3, 4, and 5, the well location was constrained to be within the half-width of the waste source. In other words, the well was always placed in the central portion of the contaminant plume where concentrations are highest. As a result, these scenarios show lower DAF values than the base case scenario. The results for Scenarios 3, 4, and 5, which differ only in the x-distance of the receptor well, show that placement of the well at either 25 or 100 feet away from the waste source results in 85% and 90% DAF values that are actually lower, i.e. more conservative, than placement of the well directly at the edge of the waste source. This is a counter-intuitive result, but may be explained from the interaction between distance from the waste source and vertical extent of the contaminant plume below the water table. Close to the waste source, the contaminant concentrations within the plume are highest, but the plume may not have penetrated very deeply into the saturated zone (Figure 2). Because the vertical position of the well was taken as a random variable, with a maximum value of up to 300 feet, the probability that a receptor well samples pristine groundwater underneath the contaminant plume is higher at close distances from the waste area. Conversely, as the distance from the source increases, the plume becomes more dilute but also extends deeper below the water table. The final result is that the overall DAF may actually decrease with distance from the source. The table also shows that at the 95% level, the lowest DAF is obtained in the case where the well is located at the edge of the waste source. This reflects that the highest concentration values will be obtained only very close to the waste source.

The results for the last scenario, in which the x, y, and z locations of the receptor well were all fixed, show that fixing the well depth at 25 feet ensures that the well is placed shallow enough that it will be located inside the plume in nearly all cases, resulting in low DAF values at the 85th and 90th percentile values. On the other hand, the well in this case is never placed immediately at the plume centerline, so that the highest concentrations sampled in this scenario are always lower than in the other scenarios. This is reflected in the higher DAF value at the 95th percentile level.

One of the key objectives of the present analyses was to determine the appropriate groundwater DAF value for a waste area of given size. For the base case scenario, the 90th percentile DAF value is on the order of 100 or higher for a waste area size of 1 acre (43,560 ft²) and less. For waste areas of 10 acres and greater, the 90th percentile DAF is 10 or less.

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APPENDIX A

Table A1 DAF values as a function of source area for base case scenario (x=25 ft, y=uniform in plume, z=nationwide distribution).

Area (sq ft)	DAF		
	85 TH	90 TH	95 TH
1000	1.09E+06	3.76E+04	609.01
2000	1.86E+05	9.63E+03	187.69
5000	2.91E+04	2.00E+03	53.02
10000	9.31E+03	680.27	22.57
30000	1647.18	155.21	7.82
50000	869.57	84.25	5.41
70000	569.80	59.28	4.34
80000	477.33	50.56	3.97
150000	237.47	26.36	2.77
200000	174.86	20.19	2.37
500000	64.52	9.12	1.61
1000000	32.27	5.61	1.32
2000000	17.83	3.68	1.16
3000000	12.94	2.94	1.11
5000000	8.91	2.33	1.06

Table A2 DAF values as a function of source area for Scenario 2 (x=nationwide distribution, y=uniform in plume, z=nationwide distribution).

Area (sq. ft)	DAF		
	85 TH	90 TH	95 TH
5000	6222.78	2425.42	565.61
8000	3977.72	1573.32	371.06
10000	3215.43	1286.01	298.78
45000	817.66	315.06	73.48
50000	745.16	288.27	67.20
100000	424.81	160.82	38.11
150000	300.12	114.71	26.82
220000	218.87	82.30	20.00
500000	110.35	40.10	10.92
1000000	63.45	23.75	6.22
5000000	21.03	7.85	2.55
6000000	19.06	7.01	2.39

Table A3 DAF values as a function of source area for Scenario 3 (x=0 ft, y=uniform within half-width of source area, z=nationwide distribution).

Area (sq. ft.)	DAF		
	85	90	95
1000	1.42E+07	2.09E+05	946.07
2000	9.19E+05	2.83E+04	211.15
5000	5.54E+04	2.74E+03	44.23
10000	1.16E+04	644.33	15.29
30000	1.43E+03	120.42	4.48
50000	668.45	60.02	3.10
70000	417.19	37.97	2.53
80000	350.39	33.16	2.34
150000	158.76	17.87	1.74
200000	114.63	12.96	1.56
500000	40.55	5.54	1.23
1000000	21.13	3.50	1.15
2000000	11.58	2.38	1.08
3000000	8.66	1.98	1.06

Table A4 DAF values as a function of source area for Scenario 4 (x=25 ft, y=uniform within half-width of source area, z=nationwide distribution).

Area (sq. ft.)	DAF		
	85	90	95
1000	5.93E+05	2.07E+04	348.31
2000	1.09E+05	4.92E+03	118.11
5000	1.64E+04	1.03E+03	29.86
10000	4.89E+03	352.49	13.14
30000	928.51	93.98	4.73
50000	490.20	49.78	3.28
70000	323.42	34.79	2.69
80000	272.85	29.82	2.47
150000	132.05	16.55	1.82
200000	97.94	12.29	1.61
500000	37.99	5.50	1.29
1000000	20.08	3.50	1.17
2000000	11.35	2.40	1.10
3000000	8.49	2.00	1.07

Table A5 DAF values as a function of source area for Scenario 5 (x=100 ft, y=uniform within half-width of source, z=nationwide distribution).

Area (sq. ft.)	DAF		
	85	90	95
1000	4.24E+04	3.43E+03	181.88
2000	1.52E+04	1.33E+03	74.79
5000	4.24E+03	437.25	27.23
10000	1.81E+03	204.29	13.09
30000	497.27	68.21	5.10
50000	293.34	40.72	3.71
70000	207.77	29.89	2.96
80000	184.57	26.86	2.73
150000	98.81	15.05	2.03
200000	74.63	11.55	1.82
500000	32.99	5.83	1.40
1000000	18.66	3.71	1.26
2000000	11.14	2.53	1.16
3000000	8.33	2.09	1.13

Table A6 DAF values as a function of source area for Scenario 6 (x=25 ft, y=source width + 25 ft, z=25 ft).

AREA (SQ FT)	DAF		
	85 TH	90 TH	95 TH
1200	44247.79	10479.98	1004.72
1500	30759.77	7215.01	744.05
5000	4789.27	1273.40	140.81
7500	2698.33	725.69	82.51
23000	637.76	155.16	21.82
26000	544.66	135.91	18.84
29000	482.63	121.43	16.52
100000	139.66	35.55	5.56
170000	76.69	21.24	3.94
250000	50.40	15.04	3.19
800000	18.10	6.04	1.81
1800000	10.26	3.87	1.48

Appendix E

Dermal and Inhalation Exposure to Contaminated Tap Water

Appendix E

Dermal and Inhalation Exposure to Contaminated Tap Water

Methodology

General Modeling Overview:

For this analysis, the same methodology that was employed for the *Non-Groundwater Pathway Risk Assessment; Petroleum Process Waste Listing Determination Notice of Data Availability* was used. Following this methodology, the maximum, modeled groundwater concentration for each constituent of concern is used as the starting concentration. Both dermal and inhalation risks are estimated based on this starting concentration. The maximum groundwater concentration is calculated using combinations of high-end parameters in the treatment train and/or high-end fate and transport parameters. Because the maximum groundwater concentration is obtained by setting combinations of parameters to high-end, including additional high-end parameters in the non-ingestion exposure model would lead to overly conservative results. Therefore, central tendency values were used, when available, as inputs in the model to avoid overly conservative risk estimations.

Exposures estimated for all indoor, household water uses. Exposure is assessed for three house compartments—exposure from being in the shower stall during and immediately after showering (both dermal and inhalation exposures), exposure from being in the bathroom after showering (inhalation exposure), and exposure from being in the rest of the house (inhalation exposure). It is assumed that all water uses for each household compartment occur while the individual is in that compartment. Average air concentrations for each house compartment are calculated and used to assess exposure from inhalation. Dermal exposures are calculated based on the starting groundwater concentration.

To develop the model that was used to address the inhalation pathway, several articles on existing models for estimating non-ingestion risks from household water uses (i.e., showering) were evaluated. Dermal exposures were estimated using the methodology presented in *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992) and *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A)* (U.S. EPA, 1989).

Description of Groundwater, Non-ingestion Exposure Model for Inhalation:

The model used in this analysis is based on the equations presented in McKone (1987). The model estimates the change in the shower air concentration based on the mass of constituent lost by the water (fraction emitted or emission rate) and the air exchange rate between the various

model compartments (shower, the rest of the bathroom, and the rest of the house) following the same basic model construct described by Little (1992). The resulting differential equations were solved using finite difference numerical integration.

The basis for estimating the concentration of constituents in the indoor air is based on the mass transfer of constituent from water to shower air.

This equation estimates the overall mass transfer coefficient from tap water to air from showering:

$$K_{ol} = \beta \times \left(\frac{2.5}{D_1^{2/3}} + \frac{1}{D_a^{2/3} H'} \right)^{-1} \quad (1-1)$$

where

- K_{ol} = overall mass transfer coefficient (cm/s)
- β = proportionality constant (cm/s)^{-1/3}
- D_1 = diffusion coefficient in water (cm²/s)
- D_2 = diffusion coefficient in air (cm²/s)
- H' = Dimensionless Henry's law constant (=41*H_{LC}).

The constituent emission rate is estimated from the change in the shower water concentration as the water falls, which is calculated using the overall mass transfer coefficient as follows:

$$\delta c / \delta t = - K_{ol} (A/V) (c - y_s / H') \quad (1-2)$$

where

- c = liquid phase (droplet) constituent concentration (µg/cm³ or mg/L)
- t = time (s)
- A = total surface area for mass transfer (cm²)
- V = total volume of water within the shower compartment (cm³)
- y_s = gas phase constituent concentration in the shower (µg/cm³ or mg/L)
- H' = dimensionless Henry's law constant.

Consequently, in addition to the overall mass transfer coefficient, the emission rate of a contaminant within the shower is dependent on the surface-area-to-volume ratio of the shower water (within the shower) and the concentration driving force between the water and the shower air.

The shower emissions can be modeled based on falling droplets as a means of estimating the surface-area-to-volume ratio for mass transfer and the residence time of the water in the shower compartment. Equation 1-2 can then be integrated assuming the compound concentration in the gas phase is constant over the time frame of the droplet fall. The time required for a droplet to fall equals the nozzle height divided by the water droplet velocity. The ratio of the surface area

to volume for the droplet is calculated as $6/d_p$ (i.e., by assuming a spherical shape). By assuming the drops fall at terminal velocity, the surface-area-to-volume ratio and the residence time can be determined based solely on droplet size. A droplet size of approximately 1 mm (0.1 cm) was selected. The terminal velocity for the selected droplet size is approximately 400 cm/s. The fraction of constituent emitted from a water droplet at any given time can then be calculated by integrating Equation 1-2 and rearranging as follows:

$$f_{em} = 1 - C_{out}/c_{in} = (1 - f_{sat})(1 - e^{-N}) \quad (1-3)$$

where

- f_{em} = fraction of constituent emitted from the droplet (dimensionless)
- C_{out} = droplet constituent concentration at shower floor/drain (mg/L)
- c_{in} = droplet constituent concentration entering the shower (mg/L)
- f_{sat} = $y_s/(H'c_{in})$ = fraction of gas phase saturation (dimensionless)
- N = dimensionless overall mass transfer coefficient = $K_{ol}(6/d_p)(h/v_t)$
- d_p = droplet diameter = 0.1 (cm)
- v_t = terminal velocity of droplet = 400 (cm/s)
- h = nozzle height (cm).

The gas phase constituent concentration in the shower is then calculated for each time step for the duration of the shower. The air exchange rate between the shower and the bathroom is included in the estimation of the gas phase concentration of the constituents in the shower.

$$y_{s,t+1} = y_{s,t} + [Q_{gs} \times (y_{b,t} - y_{s,t}) \times (t_{t+1} - t_t) + E_{s,t}]/V_s \quad (1-4)$$

where

- $y_{s,t+1}$ = gas phase constituent concentration in the shower at the end of time step (mg/L)
- $y_{s,t}$ = gas phase constituent concentration in the shower at the beginning of time step (mg/L)
- Q_{gs} = volumetric gas exchange rate between shower and bathroom (L/min)
- $y_{b,t}$ = gas phase constituent concentration in the bathroom at the beginning of time step (mg/L)
- $(t_{t+1} - t_t)$ = calculation time step
- $E_{s,t}$ = mass of constituent emitted from shower between time t and time $t+1$ (mg)
- V_s = volume of shower stall (L).

The shower model also provides direct estimates of the bathroom and whole house exposure. The risk from inhalation exposures in the remainder of the house is generally several orders of magnitude less than the risk from inhalation exposures in the bathroom and during showering. The gas phase constituent concentration in the bathroom may be estimated by Equation 1-5 for each time step of the exposure duration.

$$y_{b,t+1} = y_{b,t} + \{[Q_{gs} \times (y_{s,t} - y_{b,t})] - [Q_{gb} \times (y_{b,t} - y_{h,t})] + (I_b \times C_{in} \times f_{em,b})\} \times \left(\frac{t_{t+1} - t_t}{V_b} \right) \quad (1-5)$$

where

- $y_{b,t+1}$ = gas phase constituent concentration in the bathroom at end of time step (mg/L)
- $y_{b,t}$ = gas phase constituent concentration in the bathroom at beginning of time step
- Q_{gs} = volumetric gas exchange rate between bathroom and house
- $y_{h,t}$ = gas phase constituent concentration in the house at beginning of time step (mg/L)
- $(T_{t+1} - t_t)$ = calculation time step (min)
- I_b = bathroom water use (L/min)
- C_{in} = constituent concentration in tap water (mg/L)
- $f_{em,b}$ = fraction of constituent emitted from bathroom water use (unitless)
- V_b = volume of bathroom (L).

The gas phase constituent concentration in the remainder of the house may be estimated by Equation 1-6 for each time step of the exposure duration.

$$y_{h,t+1} = y_{h,t} + \{[Q_{gb} \times (y_{b,t} - y_{h,t})] - [Q_{gh} \times (y_{h,t} - y_{a,t})] + (I_h \times C_{in} \times f_{em,h})\} \times \left(\frac{t_{t+1} - t_t}{V_h} \right) \quad (1-6)$$

where

- $y_{h,t+1}$ = gas phase constituent concentration in the house at end of time step (mg/L)
- $y_{h,t}$ = gas phase constituent concentration in the house at beginning of time step (mg/L)
- Q_{gb} = volumetric gas exchange rate between the bathroom and house (L/min)
- $y_{b,t}$ = gas phase constituent concentration in the bathroom at beginning of time step (mg/L)
- Q_{gh} = volumetric gas exchange rate between the house and atmosphere (L/min)
- $y_{a,t}$ = gas phase constituent concentration in the atmosphere (mg/L)
- $(T_{t+1} - t_t)$ = calculation time step (min)
- I_h = house water use—other than bathroom (L/min)
- C_{in} = constituent concentration in tap water (mg/L)
- $f_{em,h}$ = fraction of constituent emitted from household water use—other than bathroom (unitless)
- V_h = volume of house (L).

The average air concentration in the shower and bathroom are obtained by averaging the concentrations obtained for each time step over the duration of the shower and bathroom use. These concentrations and the durations of daily exposure are used to estimate risk from inhalation exposures to residential use of groundwater.

Exposure Factors:

Where available, the exposure parameters used in this analysis are central tendency values cited in the *Exposure Factors Handbook* (U.S. EPA, 1996). The remaining exposure factors required for this analysis were obtained from McKone (1987). The original articles have been obtained to verify the values used in the analysis. Parameter values are presented in Table E-1.

The equation used to estimate a hazard quotient from inhalation is expressed as:

$$HQ = \frac{C_{air}}{RfC} \quad (1-7)$$

where

HQ	=	hazard quotient (unitless)
C_{air}	=	average concentration of constituent in air (mg/m ³)
RfC	=	reference concentration (mg/m ³).

Dermal Exposure to Tap Water:

Another non-ingestion route of exposure to groundwater not considered in the groundwater risk assessment for the proposed rule is dermal exposure from showering. The methodology used for assessing risk from this exposure route follows the guidelines set forth in *Dermal Exposure Assessment: Principles and Applications* (U.S. EPA, 1992) and *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (RAGS)* (U.S. EPA, 1989).

The basic equation used to calculate the contaminant dose from showering was obtained from U.S. EPA (1992) and can be expressed as:

$$DA_{event} = C_{water} \times K_p^w \left[\frac{t_{event}}{1+B} + 2\tau \left(\frac{1+3B}{1+B} \right) \right] \times \frac{1}{10^3} \quad (1-8)$$

where

DA_{event}	=	dose absorbed per unit area per event (mg/cm ²)
C_{water}	=	water concentration (mg/L)
K_p^w	=	skin permeability constant in water (cm/h)
t_{event}	=	duration of event (h)
τ	=	lag time (h)
B	=	bunge constant (unitless)
$1/10^3$	=	L/cm ³ .

**Table E-1. Exposure Factors Used to Determine Risk from
Inhalation Exposure to Contaminated Tap Water**

Exposure factor	Parameter value	Reference
Shower duration	10 min	U.S. EPA, 1997b (Table 15-20) (Represents time spent showering only)
Time in bathroom (includes shower duration, time spent in shower stall after showering, and time spent in bathroom after leaving shower stall)	40 min	U.S. EPA, 1997b (Tables 15-20, 15-23, and 15-114) (Table 15-114 represents 24-hour cumulative time spent in bathroom, which is conservative to assume that all of this time occurs immediately following the shower)
Shower rate	5.5 L/min	Calculated (based on drop diameter and nozzle velocity)
Shower/bath water use	15 gallons per capita per day (gcd)	U.S. EPA, 1997b (Table 17-14) (Median value across several studies)
Bathroom water use	35.5 gcd	U.S. EPA, 1997b (Table 17-14) (Summation of median values for <i>shower</i> , <i>toilet</i> , and one-half of the <i>other</i> water use rates; RTI assumed <i>other</i> represents water use in sinks)
House water use	17.5 gcd	U.S. EPA, 1997b (Table 17-14) (Summation of median values for <i>Laundry</i> , <i>Dishwashing</i> , and one-half of the <i>other</i> water use rates; RTI assumed <i>other</i> represents water use in sinks)
Volume of shower stall	2 m ³	McKone, 1987
Volume of bathroom	10 m ³	McKone, 1987
Volume of house	369 m ³	U.S. EPA, 1997b (Table 17-31)
Volumetric gas exchange rate between shower and bathroom	100 L/min	RTI-derived value
Volumetric gas exchange rate between bathroom and house	300 L/min	RTI-derived value
Volumetric gas exchange rate between house and atmosphere	0.45 air changes per hour (2,768 L/min)	U.S. EPA, 1997b (Table 17-31) (Median value; given a low overall confidence rating)
Fraction emitted, bathroom	0.50	Calculated
Fraction emitted, house water	0.66	Calculated
Time toilet emits	40 min/d	U.S. EPA, 1997b (Tables 15-20, 15-23, and 15-114) (Table 15-114 represents 24 hour-cumulative time spent in bathroom, which is conservative to assume that all of this time occurs immediately following the shower)
Time house water emits	15.7 h/d	U.S. EPA, 1997b (based on cumulative time spent indoors at a residence, Table 15-131, minus time spent in bathroom [see above])

From the dose absorbed, hazard quotients can be calculated for the constituents of concern by applying the following equation:

$$HQ = \frac{DA_{event} \times EF \times SA_{skin}}{RfD \times BW} \quad (1-9)$$

where

HQ	=	hazard quotient (unitless)
DA _{event}	=	dose absorbed per unit area per event (mg/cm ²)
EF	=	event frequency (showers per day)
SA _{skin}	=	surface area of skin (cm ²)
RfD	=	oral reference dose (mg/kg/day)
BW	=	body weight (kg).

No RfDs or slope factors are available for the dermal route of exposure; however, Appendix A of RAGS gives some general guidance for calculating intakes via the dermal route and making appropriate comparisons with RfDs or slope factors. In sum, oral RfDs and slope factors may need to be adjusted (depending on the constituent) based on the oral absorption efficiency of the constituent. RfDs are multiplied by the oral absorption efficiency and slope factors are divided by the oral absorption efficiency. Generally, oral absorption efficiency data are not readily available and have to be researched independently. Alternatively, US EPA Region IV has adopted the following oral absorption efficiencies as interim default values: 80% for volatile organic chemicals, 50% for semivolatile organic chemicals, and 20% for metals (US EPA, 1995).

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Appendix F

Sensitivity Analysis

Appendix F

Sensitivity Analysis

This appendix presents the results of three sensitivity analyses that were conducted to investigate parameters used in the risk analysis. These parameters are:

- area of the landfill
- depth of the landfill
- biodegradation of constituents in landfills.

The attached tables present the results of the sensitivity analysis.

Landfill Area—The results presented in this appendix indicate that the 75th and 90th percentile areas are associated with less risk than the 50th percentile landfill area for both the air pathway and the groundwater pathway. In this case, the dilution from the greater volume of municipal waste assumed disposed of in the larger landfill is greater than the effect of the smaller DAF associated with the larger landfills.

Landfill Depth—The results of the sensitivity analysis for landfill depth indicate that the maximum effect is a decrease in risk of 1 order of magnitude. The decrease in risk is due to dilution of the waste with the increased volume of the landfill. This effect is the same for both the inhalation and the drinking water pathways. There is little data on the actual depths of municipal landfills; thus, a value was chosen, based on the best professional judgment, from the Texas municipal landfill survey data. This value is compared in the sensitivity analysis to the 10th, 50th, and 90th percentile values derived from the total distribution. The effect of changes in the landfill depth is to change the capacity of the landfill in a linear fashion, which in turn changes the waste dilution factor linearly as well. These values were used because the Texas municipal landfill database was the only data source available that contained landfill depths.

Biodegradation—It is debatable whether degradation occurs in the landfill environment. Therefore, a sensitivity analysis has been conducted to determine the effect of including this loss mechanism in the risk assessment. The sensitivity analysis was conducted both with the constituent-specific biodegradation rates that were included in the risk assessment and with biodegradation set to zero for all compounds. The results of this analysis are constituent-specific: for drinking water, they range from no effect to a factor of 7; for inhalation, the inclusion of biodegradation may actually decrease risk slightly or increase it by a maximum factor of 1.5.

Sensitivity Analysis for Landfill Area: Comparing 50th Percentile Area to 75th and 90th Percentile Areas Inhalation Risk

Constituent	CAS	50th	75th	90th	Ratio of 75th Percentile Area to 50th Percentile Area Risks	Ratio of 90th Percentile Area to 50th Percentile Area Risks
Carbon tetrachloride	56-23-5	4.E-08	3.E-08	1E-08	0.6	0.3
Ethyl ether	60-29-7	NA	NA	NA	NA	NA
Methanol	67-56-1	1.E-06	8.E-07	4E-07	0.8	0.4
Acetone	67-64-1	1.E-06	6.E-07	3E-07	0.6	0.3
Butanol	71-36-3	NA	NA	NA	NA	NA
Benzene	71-43-2	2.E-08	1.E-08	7E-09	0.6	0.3
1,1,1-Trichloroethane	71-55-6	3.E-05	2.E-05	8E-06	0.6	0.3
Methylene chloride	75-09-2	2.E-09	1.E-09	5E-10	0.6	0.3
Carbon disulfide	75-15-0	5.E-05	3.E-05	1E-05	0.6	0.3
Trichlorofluoromethane	75-69-4	5.E-05	3.E-05	1E-05	0.6	0.3
Dichlorodifluoromethane	75-71-8	1.E-04	9.E-05	4E-05	0.9	0.4
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	1.E-06	7.E-07	3E-07	0.7	0.3
Isobutyl alcohol	78-83-1	NA	NA	NA	NA	NA
Methyl ethyl ketone	78-93-3	2.E-05	1.E-05	5E-06	0.6	0.3
1,1,2-Trichloroethane	79-00-5	1.E-08	9.E-09	4E-09	0.6	0.3
Trichloroethylene	79-01-6	3.E-09	2.E-09	8E-10	0.6	0.3
2-Nitropropane	79-46-9	4.E-06	3.E-06	1E-06	0.6	0.3
<i>o</i> -Xylene	95-47-6	NA	NA	NA	NA	NA
<i>o</i> -Cresol	95-48-7	NA	NA	NA	NA	NA
1,2-Dichlorobenzene	95-50-1	1.E-06	9.E-07	4E-07	0.9	0.4
Nitrobenzene	98-95-3	9.E-05	6.E-05	3E-05	0.6	0.3
Ethylbenzene	100-41-4	6.E-06	4.E-06	2E-06	0.6	0.3
<i>p</i> -Cresol	106-44-5	NA	NA	NA	NA	NA
Methyl isobutyl ketone	108-10-1	1.E-04	7.E-05	3E-05	0.7	0.3
<i>m</i> -Xylene	108-38-3	NA	NA	NA	NA	NA
<i>m</i> -Cresol	108-39-4	NA	NA	NA	NA	NA
Toluene	108-88-3	3.E-05	2.E-05	9E-06	0.7	0.3
Chlorobenzene	108-90-7	3.E-04	2.E-04	7E-05	0.5	0.2
Cyclohexanone	108-94-1	NA	NA	NA	NA	NA
2-Ethoxyethanol	110-80-5	3.E-06	2.E-06	8E-07	0.6	0.3
Pyridine	110-86-1	2.E-04	1.E-04	6E-05	0.6	0.3
Tetrachloroethylene	127-18-4	8.E-05	5.E-05	2E-05	0.6	0.3
Ethyl acetate	141-78-6	NA	NA	NA	NA	NA
Xylenes (total)	1330-20-7	9.E-06	6.E-06	3E-06	0.6	0.3

Sensitivity Analysis Performed for Examining the Effect of Landfill Depth on the Risk from the Ingestion of Drinking Water

Constituent	CAS	Risk Results for the Central Tendency Analysis				Risk Ratio Compared to the Results from the Original Analysis			
		Original	10th %ile	50th %ile	90th %ile	10th %ile	50th %ile	90th %ile	
Carbon tetrachloride	56-23-5	6E-07	9E-07	3E-07	2E-07	1.4	0.6	0.2	
Ethyl ether	60-29-7	5E-02	5E-02	2E-02	7E-03	1.2	0.4	0.2	
Methanol	67-56-1	5E-02	5E-02	5E-02	4E-02	1.0	1.0	0.7	
Acetone	67-64-1	2E-01	2E-01	2E-01	2E-01	1.0	1.0	1.0	
Butanol	71-36-3	2E-01	2E-01	9E-02	4E-02	1.0	0.5	0.2	
Benzene	71-43-2	3E-06	4E-06	1E-06	6E-07	1.4	0.5	0.2	
1,1,1-Trichloroethane	71-55-6	4E-04	5E-04	2E-04	8E-05	1.3	0.5	0.2	
Methylene chloride	75-09-2	3E-06	5E-06	2E-06	8E-07	1.4	0.5	0.2	
Carbon disulfide	75-15-0	9E-03	2E-02	5E-03	2E-03	2.0	0.5	0.2	
Trichlorofluoromethane	75-69-4	2E-04	3E-04	8E-05	4E-05	1.5	0.5	0.2	
Dichlorodifluoromethane	75-71-8	6E-04	9E-04	3E-04	9E-05	1.4	0.4	0.1	
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	3E-06	4E-06	9E-07	5E-07	1.3	0.3	0.2	
Isobutyl alcohol	78-83-1	5E-02	6E-02	4E-02	2E-02	1.2	0.7	0.3	
Methyl ethyl ketone	78-93-3	4E-02	4E-02	3E-02	2E-02	1.0	0.8	0.5	
1,1,2-Trichloroethane	79-00-5	2E-06	2E-06	9E-07	3E-07	1.4	0.5	0.2	
Trichloroethylene	79-01-6	7E-08	9E-08	3E-08	1E-08	1.4	0.5	0.2	
2-Nitropropane	79-46-9	NA	NA	NA	NA	NA	NA	NA	
<i>o</i> -Xylene	95-47-6	7E-05	9E-05	4E-05	9E-06	1.3	0.5	0.1	
<i>o</i> -Cresol	95-48-7	2E-02	3E-02	9E-03	4E-03	1.5	0.5	0.2	
1,2-Dichlorobenzene	95-50-1	2E-04	2E-04	7E-05	3E-05	1.0	0.4	0.2	
Nitrobenzene	98-95-3	9E-01	9E-01	5E-01	2E-01	1.0	0.5	0.2	
Ethylbenzene	100-41-4	9E-04	2E-03	5E-04	2E-04	2.0	0.6	0.2	
<i>p</i> -Cresol	106-44-5	4E-01	5E-01	2E-01	7E-02	1.5	0.5	0.2	
Methyl isobutyl ketone	108-10-1	9E-02	9E-02	5E-02	2E-02	1.0	0.6	0.2	
<i>m</i> -Xylene	108-38-3	6E-05	8E-05	3E-05	9E-06	1.3	0.4	0.1	
<i>m</i> -Cresol	108-39-4	4E-02	5E-02	2E-02	6E-03	1.3	0.5	0.2	
Toluene	108-88-3	9E-04	9E-04	5E-04	2E-04	1.0	0.5	0.2	
Chlorobenzene	108-90-7	3E-03	4E-03	9E-04	5E-04	1.3	0.3	0.2	
Cyclohexanone	108-94-1	4E-03	5E-03	2E-03	8E-04	1.3	0.5	0.2	
2-Ethoxyethanol	110-80-5	7E-02	7E-02	5E-02	3E-02	1.0	0.8	0.4	
Pyridine	110-86-1	2E+01	2E+01	9E+00	5E+00	1.0	0.5	0.3	
Tetrachloroethylene	127-18-4	5E-03	5E-03	3E-03	9E-04	1.2	0.6	0.2	
Ethyl acetate	141-78-6	2E-02	2E-02	9E-03	5E-03	1.0	0.5	0.3	
Xylenes (total)	1330-20-7	4E-05	5E-05	2E-05	6E-06	1.3	0.5	0.2	

Sensitivity Analysis for the Effect of Including Degradation in the Landfill in the Risk Analysis for the Ingestion of Drinking Water

Constituent	CAS	Leachate - No Degradation	Drinking Water - No Degradation	Leachate - Degradation	Drinking Water - Degradation	Ratio No Degradation: Degradation Included
Carbon tetrachloride	56-23-5	5.E-05	4.E-06	7.E-06	6.E-07	7.0
Ethyl ether	60-29-7	5.E-01	5.E-02	5.E-01	5.E-02	1.0
Methanol	67-56-1	7.E-01	6.E-02	6.E-01	5.E-02	1.2
Acetone	67-64-1	3.E+00	3.E-01	2.E+00	2.E-01	1.5
Butanol	71-36-3	2.E+00	2.E-01	2.E+00	2.E-01	1.0
Benzene	71-43-2	4.E-05	4.E-06	3.E-05	3.E-06	1.5
1,1,1-Trichloroethane	71-55-6	2.E-02	2.E-03	4.E-03	4.E-04	5.0
Methylene chloride	75-09-2	6.E-05	5.E-06	4.E-05	3.E-06	1.6
Carbon disulfide	75-15-0	1.E-01	9.E-03	1.E-01	9.E-03	1.0
Trichlorofluoromethane	75-69-4	1.E-02	9.E-04	2.E-03	2.E-04	5.0
Dichlorodifluoromethane	75-71-8	4.E-02	4.E-03	7.E-03	6.E-04	5.7
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	3.E-05	3.E-06	3.E-05	3.E-06	1.0
Isobutyl alcohol	78-83-1	7.E-01	6.E-02	6.E-01	5.E-02	1.2
Methyl ethyl ketone	78-93-3	4.E-01	4.E-02	4.E-01	4.E-02	1.0
1,1,2-Trichloroethane	79-00-5	1.E-04	1.E-05	2.E-05	2.E-06	6.9
Trichloroethylene	79-01-6	5.E-06	5.E-07	7.E-07	7.E-08	7.0
2-Nitropropane	79-46-9	NA	NA	NA	NA	NA
<i>o</i> -Xylene	95-47-6	8.E-04	7.E-05	8.E-04	7.E-05	1.0
<i>o</i> -Cresol	95-48-7	4.E-01	4.E-02	2.E-01	2.E-02	2.0
1,2-Dichlorobenzene	95-50-1	9.E-03	8.E-04	2.E-03	2.E-04	4.5
Nitrobenzene	98-95-3	6.E+01	5.E+00	1.E+01	9.E-01	6.0
Ethylbenzene	100-41-4	1.E-02	9.E-04	1.E-02	9.E-04	1.0
<i>p</i> -Cresol	106-44-5	5.E+00	5.E-01	4.E+00	4.E-01	1.3
Methyl isobutyl ketone	108-10-1	1.E+00	9.E-02	1.E+00	9.E-02	1.0
<i>m</i> -Xylene	108-38-3	7.E-04	6.E-05	7.E-04	6.E-05	1.0
<i>m</i> -Cresol	108-39-4	4.E-01	4.E-02	4.E-01	4.E-02	1.0
Toluene	108-88-3	2.E-02	2.E-03	1.E-02	9.E-04	2.0
Chlorobenzene	108-90-7	1.E-01	9.E-03	3.E-02	3.E-03	3.3
Cyclohexanone	108-94-1	4.E-02	4.E-03	4.E-02	4.E-03	1.0
2-Ethoxyethanol	110-80-5	1.E+00	9.E-02	8.E-01	7.E-02	1.3
Pyridine	110-86-1	2.E+02	2.E+01	2.E+02	2.E+01	1.0
Tetrachloroethylene	127-18-4	3.E-01	3.E-02	5.E-02	5.E-03	6.0
Ethyl acetate	141-78-6	2.E-01	2.E-02	2.E-01	2.E-02	1.0
Xylenes (total)	1330-20-7	7.E-04	6.E-05	4.E-04	4.E-05	1.8